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EFFECT OF BLADE DESIGN IN THE LOUVER TYPE DUST SEPARATOR

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Joseph A. Ogle

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LOUVER TYPE DUST SEPARATOR

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SUMMARY

The investigation was conducted primarily to determine what effect louver blade shape, proportion and spacing has on the performance of the louver type dust separator. Coincident with the primary investigation, the effects of dust particle density and the location of the back wall with respect to the louver blade were also studied.

The effect of louver blade shape was determined by testing eight different individual louver blades. The test blades were constructed so that features believed to effect separation were varied in such a way that the effect of each feature could be determined. Each blade was tested under varying conditions of dust concentration that simulate conditions in an actual dust separator. Additional tests were conducted with selected blades using a dust with a mass density much lower than that used in the original tests. With three blades the distance from the back wall was varied and the effect on the performance of the blades observed and compared.

The louver blade shape was found to effect the performance of the dust separator in two ways; first, the blade shape effects the pressure drop across the louver opening for any fixed flow rate through the opening, and second, the blade shape effects the efficiency of the blade in removing dust particles from the air. The most revealing feature of the investigation was that, with other conditions being equal, the blade that operated with the lowest pressure drop across the louver opening also was the most efficient in removing dust particles from the air. Of all the

blades tested the one with a curvilinear profile approximating that of a convergent nozzle gave the best performance.

The effect of the mass density of the dust particles had a very pronounced effect on the efficiency of dust separation. The efficiency of the blade was considerably less in removing particles that weighed nine pounds per cubic foot than for particles weighing two hundred fifty eight pounds per cubic foot. Only two types of dust were tested thus the relationship between mass density and the efficiency of the louver blade was not determined.

The location of the back wall with respect to the louver blade was found to have relatively little effect on the efficiency of the louver blade in removing dust particles from the air.

CHAPTER I

INTRODUCTION

The Problem.--The practicality of the louver type dust separator has been demonstrated numerous times. It employs the simple fact that the kinetic energy of a moving dust particle is greater than the kinetic energy of an equal volume of air moving with the same velocity. The louver blades of the separator are arranged so that the air is deflected through the openings between the blades while the greater kinetic energy of the dust particles force them past the openings. Several separators of this type have been made and used for some time.

Some studies of the mechanism of separation in the louver separator have been made and the paths of the dust particles theorized. However, the limitations imposed in this theoretical work limit the use of these studies when applied to the practical design of louver blades.

The problem undertaken in this investigation was the determination of the effect of louver blade shape, spacing and proportion on the mechanism of dust separation.

Previous Work.--Harwell (1) in 1950, Matheson (2) in 1952 and Smith (3) in 1953 submitted, at the Georgia Institute of Technology, theses on the louver dust separator. Harwell and Matheson made detailed analyses of performance data from separators employing flat blades. A literature search by Matheson showed that very little had been published about the mechanism of separation or the design of these separators. Smith analyzed the path of a dust particle for two idealized conditions and discovered some of the weaknesses of the flat blades and the louver housings used by Harwell and Matheson. Smith then built and tested a louver separator employing blades that had a 45 degree lip formed on the down stream edge to deflect the dust particles away from the louver openings. These blades were employed in a louver housing that maintained a constant velocity of the dust laden air down the louver face.

Objective.--The principal objective of this investigation was to determine the effect of various louver blade shapes on the mechanism of dust separation. This involved the analysis of experimental data obtained from an apparatus designed to test selected individual louver blade elements. Additional objectives were to determine the effect of the back wall location and the mass density of the dust particles on the mechanism of separation.

CHAPTER II

PRELIMINARY STUDIES

Studies of J. L. Smith.--The most thorough study of the mechanism of separation in the louver type dust separator was conducted by Smith (3) in 1953. Prior to that time all known experiments with the louver dust separator had been made using a series of straight blades or vanes arranged at an angle to the direction of flow of the dust laden air down the louver face (4). Smith observed that this arrangement caused the dust particles to strike the louver blades in the immediate area of the opening between the blades with the result that these particles were subjected to the drag of the air passing through the louver openings. Particles that for any reason did not rebound from the louver face with sufficient velocity and in the proper direction were carried through the louver opening and not separated. The observation was made that if the velocity of the dust laden air decreased (and the pressure in the air stream was thus increased) as it moved down the louver face the down stream blades became less effective in separating dust. This was particularly objectionable since the concentration of dust increases as the dust laden air moves down the louver face.

Based on these observations Smith built and tested a separator using blades embodying a straight section parallel to the direction of flow of the dust laden air and with a 45 degree lip formed on the down stream edge. The blades were arranged in the separator so that the opening between the blades was immediately down stream from the 45 degree lip and the projected area of the lip in the direction of flow of the dust laden air was equal to the area of the opening between the blades. This arrangement removed the point of impact of the dust particles with the blade from the immediate area of the opening between the blades. The separator housing was designed so that the velocity of the dust laden air down the louver face would be constant and the velocity of cleaned air through each of the openings between the louver blades would be the same. Smith also developed an analytical equation for the path of a particle in the dust laden air stream as it moves past a louver opening and an equation for the path of a particle after impact with the louver blade. These indicate that the mechanism of separation is independent of the initial velocity of the dust laden air down the louver face but is dependent on the ratio of the velocity through louver opening to the velocity down the louver face. The equations also indicate that the size and density of the particle will effect separation.

As a result of his analysis and tests Smith concluded that the per cent of dust separated was essentially independent of the initial velocity of the dust laden air if this velocity was maintained down the entire louver face and that the per cent of dust separated was essentially independent of the initial concentration of dust. The studies also showed that the separator was effective for particles as small as ten microns and that it would perform effectively with a very low pressure loss if the initial velocity of the dust laden air were sufficiently reduced. Smith also believed that the drag created by the walls bounding the louver blades may have slowed the air along these surfaces to a degree that adversely effected the efficiency of the separator and that the rebound of particles from the back wall opposite the louver face had the same effect.

Conclusions from Preliminary Studies.—From the preliminary studies it is concluded that the per cent separation in the louver dust separator is essentially independent of the initial dust concentration and the initial velocity of the dust laden air. It is also concluded that the shape, proportion and spacing of the individual louver blades have a definite but undetermined effect on the mechanism of separation. The wall opposite the louver face and those at the ends of the louver blades may have some effect on the mechanism of separation. Size and density of the dust particles do have an effect on the mechanism of separation that can be predicted by approximate formulae (5).

CHAPTER III

LOUVER BLADE DESIGN

Louver Blade Function.—The function of the blade of the louver dust separator is to cause the dust particle to move away from the louver face and at the same time permit the air in the immediate vicinity of the louver face to pass through the openings between the blades. The movement of the dust away from the louver face should be accomplished with the least possible loss in kinetic energy in the air and in the dust particles. It should also be accomplished in such a way that it will eliminate the possibility of a "chance" rebound from the louver blade that would direct a dust particle through the louver opening. In addition any particle that passes over an opening between two louver blades should be moving in such a direction and with sufficient momentum to prevent its being drawn through the opening by the drag of the cleaned air.

In order to analyze the motion of a dust particle Smith developed two formulae (5) that give the idealized path of a particle subjected to the measurable conditions in the louver type dust separator. For a particle that just misses the tip of one blade and passes over the opening between two blades with an initial velocity equal to that of the inlet air and in the same direction as the inlet air the approximate formula for the particle path is

$$y = \frac{D \rho_p}{0.33 \rho_a} \left\{ \frac{V_y}{V_x} \left(e^{\frac{0.33 \rho_a x}{D \rho_p}} - 1 \right) - \ln \left[\frac{V_y}{V_x} \left(e^{\frac{0.33 \rho_a x}{D \rho_p}} - 1 \right) + 1 \right] \right\}$$

where D = the diameter of the particle

ρ_p = the density of the dust particle

ρ_a = the density of the air

V_y = the velocity of the air through the louver opening

V_x = the velocity of the air down the louver face

x = the distance parallel to flow of inlet air

y = the distance normal to flow of inlet air

The origin of the coordinate system is at the tip of the blade just missed by the particle.

For a particle that rebounds from the inclined section of the louver blade the particle path is given by the formula

$$x = \frac{D\rho_p}{0.33\ \rho_a}\left\{\frac{V_x}{V_{yo}}\left(e^{\frac{0.33\ \rho_a y}{D\rho_p}} - 1\right) - \ln\left[\frac{V_x}{V_{yo}}\left(e^{\frac{0.33\ \rho_a y}{D\rho_p}} - 1\right) + 1\right]\right\}$$

where V_{yo} = y velocity of the particle after impact

As Smith points out these formulae are only approximations and assume initial conditions that are hypothetical. However, they do indicate the physical features of the dust particle and the blade design that have the major effect on the mechanism of separation. From the first formula it can be seen that the diameter and the density of the dust particle and the ratio of the velocity of the air through the louver opening to the velocity of the dust laden air down the louver face will effect the particle path. From the second formula it is seen that in addition to these same factors the velocity of the particle normal to the direction of flow of the inlet air will effect the path of a particle after impact with the louver blade.

Many other factors that effect the mechanism of separation cannot readily be included in an analytical formula. They include the conditions of impact of the dust particle with the louver blade, the effect of impact between dust particles, the location of any impact with respect to the louver opening and the effects of turbulence in the dust laden air stream. If separation could be effected in such a way that these factors could be eliminated or their detrimental effects reduced the efficiency of the separator should be improved.

Since it can be assumed that all impacts, whether between particle and blade or between particles, would cause a loss of kinetic energy any configuration that would reduce the number of impacts or the violence with which impact occurs would reduce this energy loss. If this same configuration would effectively move the particles away from the louver face the efficiency of the separator would be improved. Similarly, if the energy loss that occurs in the air mass as a result of molecular impact could be reduced there should be less pressure drop across the louver opening and the power required for separation would be reduced. Assuming that impact between particles and the blade and between particles cannot be eliminated then it should be made to occur in a region that will allow the drag of the air down the louver face to accelerate the particle to near its' original velocity down the louver face by the time it passes over an opening between the louver blades. The harmful turbulence in the dust laden air can probably be reduced by incorporating in the louver blade design features that are known to improve the flow characteristics in ducts and nozzles.

Louver Blade Design.--The effect of particle size and density can only be evaluated for any given louver blade design but most of the other factors that effect separation can be accounted for in the design of the louver blade.

The velocity of the dust laden air down the louver face can be controlled by changing the cross sectional area of the dust laden air passage after each louver opening. The ratio of the velocity of the air through the louver opening to the velocity down the louver face can be controlled by the pressure drop that is allowed across the opening and by the width of the opening. Although no way is seen to eliminate the impact of dust particles on the louver blade the adverse effects of the impact could possibly be lessened by reducing the angle of impact between the blade and the particle or by employing a curved blade where the particles may strike the blade at a very small angle and then slide or roll along the surface of the blade. This curved blade could also be used to reduce the harmful impact of air jets in the dust laden air. The distance between the point of impact and the louver opening could be increased by adding a straight section of blade parallel to the direction of flow of the inlet air before the louver opening.

The louver blade shape that will give the optimum performance cannot be designed from analytical or empirical equations available at the present time.

CHAPTER IV

SELECTION OF LOUVER BLADES FOR INVESTIGATION

Louver Blade Profiles.--Two factors were considered in the selection of profiles for the louver blades to be investigated. They were the feasibility of making the blades with the equipment available and what profiles would provide the most information about the mechanism of separation.

Sheet metal working equipment was available that could form angles up to 90 degrees and form accurate curved surfaces with a radius as small as 0.5 inches. In addition to this standard equipment a jig was made that would insure accurate positioning of the parts of the louver blade assembly during the assembling process. The jig made it possible to hold a tolerance of plus or minus 1/64 inch as the parts were spot welded together. All of the blades were made of 24 gage steel. The overall dimensions of the assembly was 9 inches in the direction of flow of the inlet air and 6 inches normal to this flow.

Eight profiles, Figures 1, 2 and 3, were selected for the tests and all but one of these employed a 45 degree lip formed on the down stream edge of the blade. The lip on the eighth blade was formed as the arcs of a circle with a 0.5 inch radius. Only one opening was provided in any blade assembly even though three lips were formed on some of the blades to create a flow pattern that would approximate that found in a multiblade separator. The maximum width of this opening was 0.5 inches for any blade assembly and the ratio of the length to width of this opening was 12 to 1 or greater in all cases. It was thus believed that the effect of the end walls would be negligible. The length of the straight section before the lip on the blade varied from 0.88 inches to over 50 inches. The frontal area of the blade lip was 0.25 square inches per inch of length for five of the assemblies and was 0.5 square inches per inch of length for the other three. The ratio of the lip frontal area to the blade open area was 1 to 1 for six of the assemblies, and 2 to 1 and 2 to 3 for the other two.

Dust Samples Selected.--The dust samples selected for the test varied greatly in density but had approximately the same particle size distribution. The dust with the highest mass density was Norton Company's Alundum 240 grit abrasive. It has a mass density of approximately 258 pounds per cubic foot. The particles, Figure 5, were angular and presented many sharp corners. The particle size distribution of this dust is shown in Figure 6. The low density dust selected was Bakelite Company's Microballons. This material is made to float on the surface of oil storage tanks to prevent evaporation. The mass density of the Microballons is approximately 9 pounds per cubic foot. The majority of the particles, Figure 7, are spherical. The particle size distribution of this dust is shown in Figure 8.

CHAPTER V

APPARATUS

The Air System.--The apparatus was built entirely from new materials and Figures 13 thru 17 show the layout of the equipment.

Air for the tests was supplied by a single stage Type "F" American Blower Company pressure fan, Model 6-28. The fan was powered by a fifteen horsepower, 3500 RPM motor. This provided an available supply of 640 cubic feet of free air per minute at a pressure of 53 inches of water. The volume of air supplied was controlled by a conical valve in the ten inch inlet duct of the fan. The fan was located near a wall and the inlet duct was connected to the fan by a 90 degree elbow.

From the outlet of the fan the air passed into a section of six inch steel pipe 80 inches long. This was connected to a 20 inch length of the same diameter pipe by pressure tap flanges. An orifice plate for measuring the flow of air in the pipe was placed between the two flanges. In order to keep the length of pipe between the fan and the orifice to a minimum a straightening vane was installed in the 80 inch length of pipe in accordance with the recommendations of Stearns, Jackson, Johnson and Larson (6). The vane was constructed from nineteen 12 inch lengths of one inch diameter thin wall electrical conduit. These were soldered into a bundle and held in the six inch pipe by two set screws. The outlet of the vane was located 37 inches upstream from the orifice plate. The air passed from the 20 inch length of pipe through a transition section that changed the cross section of the pipe from a six inch diameter circle to a six inch square. This transition section was 16 inches long and provided a maximum divergence of less than 4 degrees along any line parallel to the direction of flow

Dust Feed Mechanism.—A dust feed mechanism, Figure 16, was arranged to discharge into the transition section at a point 6 inches downstream from the end of the six inch pipe. Compressed air from the laboratory system was used to inject the dust into the main air stream. The dust hopper was mounted above the injector on three rods one eighth inch in diameter so that the vibration of the apparatus caused the dust hopper to vibrate in such a way that the dust flow was at a uniform rate. The rate at which the dust could be injected was controlled by a conical valve in the bottom of the dust hopper. The flow rates could be varied from 25 grams per minute to 750 grams per minute for Norton Company's 240 grit Alundrum and from 50 grams per minute to 240 grams per minute for Bakelite Company's Microballons.

Test Section.—The test section was constructed to receive the test blade assemblies, Figure 4, and to provide a movable wall opposite these assemblies. The section was constructed of Masonite and wood and was 84 inches long and 6 inches high throughout this length. A two sided venturi arranged in the horizontal plane reduced the 6 inch square inlet of the section to a 3 inch by 6 inch throat in the first 3 inches of the section. One side of the section was extended from the venturi throat with no divergence. The test blade assemblies were mounted in this side at a point 52 inches from the throat. The opposite side was hinged at the venturi throat and could be moved to change the divergence angle from zero degrees to a maximum of 3.5 degrees. The movable wall was jointed at a point 46 inches down stream from the venturi throat by a flush hinge and the last 35 inches of the movable wall was held parallel to the opposite stationary side. Twenty inches beyond the test blade assemblies the blowdown air and dust entered a blowdown filter bag through a 6 inch long transition section. The blowdown filter bag was approximately 16 inches in diameter and was 60 inches long. It was made by sewing two standard U.S. Army duffle bags together end to end.

The cleaned air made a 180 degree change in direction in passing through the test blade assemblies and entered a rectangular duct with a cross section of 6 inches by 1-1/8 inches. This duct was changed by a transition section into a round tube 1-1/2 inches in diameter in approximately seven inches of length. The round tube was 10 inches long and conducted the cleaned air into a dust bag in the cleaned air dust collecting chamber.

Cleaned Air Dust Collecting Chamber.---The purpose of the cleaned air dust collecting chamber, Figure 17, was to remove, by filtration, any dust that may have escaped separation by the test blade assembly. The device consisted of a holder for a disposable Electrolux vacuum cleaner bag, an inlet tube from the test blade assemblies, and an outlet pipe to a rotameter. The Electrolux bag was provided with a perforated rubber diaphragm that sealed the bag to the inlet tube. After passing through the bag the air was collected in a cylindrical can 8 inches in diameter and 12 inches high that surrounded the bag and directed by a hinged conical section on top of the cylinder into a 1-1/2 inch steel pipe that lead to a rotameter. The cylindrical and conical sections of the chamber were sealed by an "O" ring to prevent the loss of air and to permit the removal of the Electrolux bag for weighing.

Flow Meters.—One orifice flowmeter and one rotameter were incorporated in the apparatus. The orifice meter was placed in the 6 inch diameter pipe to measure the volume of air entering the test section. The orifice meter was a flange tap installation with 1/2 inch pressure taps located 1 inch up stream and 1 inch down stream from the center of the orifice plate. The flanges, gaskets and orifice plate were purchased from the Foxboro Company, Foxboro, Mass., and installed in accordance with the manufacturers instructions[1]. The pressure differential across the orifice plate and the static pressure up stream from the plate were measured by "U" tube manometers filled with water.

The cleaned air was measured with a rotameter flow rater. The meter used was a Schutte and Koerting model 18200 Safeguard Rotameter. The meter had a range of from zero to fifty two cubic feet per minute. The meter was calibrated by the manufacturer[2] and provided with a calibration correction chart to correct for inlet conditions different from those for which the meter was calibrated.

Miscellaneous Equipment.—A wet-dry bulb thermometer, a barometer, a balance sensitive to 0.1 gram, a chainomatic balance sensitive to 0.001 gram and a stop watch were also used during the conduct of the tests.

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[1]The Foxboro Company, Foxboro, Mass., bulletin 6-110 dated July 1941.

[2]Schutte and Koerting Company, Cornwells Heights, Bucks County, Pa.

CHAPTER VI

TEST PROCEDURE

Each test blade assembly was tested by varying the dust concentration in the inlet air stream. Five runs, each with a different dust concentration, were made. On each of the five runs 300 grams of dust were injected into the inlet air stream and the rate of injection was varied to give the desired concentration.

Prior to the start of any test five dust samples were prepared in individual containers and five Electrolux vacuum cleaner bags used to filter the cleaned air were weighed. To minimize the hygroscopic change in weight of the dust and bags they were placed in a room where the temperature was held at 66 degrees, plus or minus 1 degree, and the humidity was held at 58 per cent, plus or minus 1 per cent, for a period of at least 12 hours before weighing. In this room the dust was spread in a thin layer and the bags were expanded to expose the greatest possible area to the atmosphere. The dust samples were weighed on a balance sensitive to 0.1 gram and the bags were weighed on a balance sensitive to 0.001 gram. At the time of weighing a "control" bag was also weighed. It was subjected to the same treatment as the other bags except that no dust was collected in it. At the completion of the runs the five filter bags and the "control" bag were returned to their former positions in the constant temperature room for a period of at least 12 hours before reweighing. At the time of reweighing the "control" bag was used as a standard to correct for any hygroscopic weight change that may have occurred.

The louver blade assembly to be tested was bolted in the apparatus and all the cracks around the periphery were sealed with putty to prevent the passage of air and dust except the louver slot. The blower was started and run until the temperature of the air at the inlet air orifice had risen about 40 degrees above room temperature. The compressed air for the dust injector was then adjusted to 25 pounds per square inch gage pressure and the air flow rates through the apparatus were adjusted. The dust hopper valve was set for the desired dust concentration and the first of the weighed bags was placed in the cleaned air filter. The flow rates were then rechecked and adjusted if necessary and all manometers, thermometers and the rotameter were read and the readings recorded. At this time the weighed sample of dust was poured into the dust hopper and the time required for injection into the inlet air stream was recorded. At the completion of the run the cleaned air filter bag was removed from the filter and the second bag placed in the filter. The dust hopper valve was set for a higher discharge rate and necessary flow rate adjustments were made. All meter readings were again recorded and the second dust sample was injected. This procedure was repeated for each of the five runs. At the completion of the five runs the apparatus was shut down and the blowdown dust bag was emptied and the louver blade assembly was changed.

A total of eight different blade assemblies were tested with Norton Company's "Alundum" 240 grit abrasive as the dust and three blades were tested with Bakelite Company's "Microballons" as the dust.

To test the effect of the back wall on the mechanism of separation a number of runs were made in which the back wall of the apparatus was moved 1 inch closer to the louver blade for each successive run. During these tests the weight of dust injected was changed for each run so that the dust concentration in the inlet air stream was approximately the same for each run. Three blades were tested to determine the effect of the back wall location.

CHAPTER VII

DISCUSSION OF RESULTS

General.—In the tests using Alundum 240 grit dust the small mass of dust recovered by the cleaned air filter bags made accurate weighing of these bags the most critical measurement of the tests. Extreme care was taken in the weighing procedure to account for hydroscopic effects but other unaccountable losses affected the weight of the filter bags in an unpredictable way. To determine the maximum effect of this unaccountable weight change five bags were placed in the apparatus and run for periods of from one to six minutes with no dust being injected and weighed in the same manner as the other test bags. The results of this test, Table 6, show that the unaccounted for weight change should not exceed plus or minus 15 milligrams. For any individual run that was made this would result in an error in the calculated efficiency of the test blade not greater than plus or minus 0.2 per cent. The small mass of dust recovered also made it impossible to determine the particle size distribution of the dust that escaped separation by the louver blade. No loose dust could be found in any of the filter bags and an examination of the inner surface of the bag used in run number 5 showed approximately one dust particle imbedded in the inner surface for each five square centimeters of surface examined.

In the tests using Microballons the efficiency of the louver blades was much lower and the weight of dust that escaped separation was approximately twenty times as great as for Alundum. The error in efficiency resulting from the unaccountable change in weight in these tests is less than plus or minus 0.03 per cent and sufficient dust was filtered out of the cleaned air to permit determination of the particle size distribution.

Efficiency.—The efficiency shown in column 6 of Table 5 represents the percentage dust in the inlet air that was separated by the louver blade and is given by the expression

$$\text{Eff.} = 100.00 - \frac{c_3}{c_2} \times 100$$

where c_2 = lb. dust/lb. air, in the initial air

c_3 = lb. dust/lbs. air, in the cleaned air.

Effect of Air Velocities.—Since it had been concluded from the preliminary studies that the initial velocity of the dust laden air had very little effect on the mechanism of separation no deliberate attempt was made to vary this velocity. However, the increased resistance of the blow down bag during the test of each blade made it necessary to vary either the inlet velocity slightly or to change the rate of flow through the louver blade assembly and increase the pressure in the apparatus. It was decided to let the inlet velocity vary and keep the rate of flow through the louver blade assembly constant for each test.

From the equations discussed in Chapter III it is seen that as the ratio of the velocity between the blades to the velocity down the louver face increases the efficiency of the louver blade will decrease. Thus for these tests the velocity down the louver face decreases with each successive run while the velocity between the blades is constant and a decrease in efficiency was expected for each successive run. As shown in Table 5 and in Figures 18, 19 and 20 this expected decrease in efficiency did occur.

Effect of Dust Concentration.--Even though it had been anticipated that the effect of the initial concentration of dust had little effect on the mechanism of separation the dust concentrations were changed for each run to approximate what might exist at five intervals down the face of a series of louver blades. For most of the tests this concentration was increased for each successive run. In the test of blade assembly #8 with Microballons this was reversed and the concentration was decreased for each successive run. As can be seen from Figure 20 this had little effect compared to the effect of velocity ratio and the original conclusion is believed valid.

Effect of Dust Particle Density.--Norton Company's Alundum 240 grit abrasive with a density of approximately 258 pounds per cubic foot and Bakelite Company's Microballons with a density of approximately 9 pounds per cubic foot were used in these tests.

The formulae discussed in Chapter III predict that the efficiency of separation will be decreased by a decrease in the density of the dust particles. This effect for the three blade assemblies tested with both Alundum and Microballons dust can be seen in Figures 18, 19 and 20. The tests showed that not only is the efficiency greatly reduced with the low density particles but also that the effect of the velocity ratio is much more pronounced.

The mean particle size of the Alundum dust is 71 microns and of the Microballons is 64 microns and in general the Microballons are spherical whereas the Alundum particles are angular. These variations in mean size and in shape will have some effect on the mechanism of separation but it is believed to be small compared to the density effect.

Effect of Louver Blade Shape.--The shape and proportion of the louver blades effected the results obtained in two ways; in the efficiency of the louver blade in separating the dust particles from the air and in the pressure drop across the louver blade opening.

A comparison of the results of runs, 6 thru 10 with blade assembly #2, 16 thru 20 with blade assembly #4 and 36 thru 40 with blade assembly #8, show that the blade shape requiring the least pressure drop for the same flow rate is also the most efficient in separating dust particles from the air. For all of these runs the frontal area before the louver opening, the area of the opening between the blades and the rate of flow through the opening were the same. The same effect is also observed by comparing runs 46 thru 50 and 51 thru 55 where Microballons were used.

The effect of varying the width of the opening between the louver blades can be seen by comparing runs 11 thru 15, 26 thru 30 and 31 thru 35. The blade assemblies were the same except for the openings which were 0.25, 0.12 and 0.37 inches respectively. The tendency here is the same as that described above with the efficiency of the louver blade being highest for the louver blade that has the lowest pressure drop for the same velocity of flow through the opening. It should be noted that there was an angle of 15 degrees between the trailing edge of one blade and the leading edge of the next for all of these blades.

The effect of changing the length of the straight section of the blade before the lip can be seen by comparing runs, 1 thru 5 with blade assembly #1, 11 thru 15 with blade assembly #3 and 21 thru 25 with blade assembly #5. In each of these blade assemblies all dimensions were the same except the length of the straight section before the lip. Here again the tendency is for the efficiency to be highest for the louver blade that causes the lowest pressure drop across the opening for the same flow rate.

It was expected that a blade shape approximating the convergent section of a nozzle, blade assembly #8, would cause much less turbulence in the air stream down the louver face and would probably cause less pressure drop across the louver opening for the same flow rate. A comparison of runs 16 thru 20 to runs 36 thru 40 and of runs 46 thru 50 to runs 51 thru 55 show that there was considerably less pressure drop across the opening in blade assembly #8 than in the other blade with a lip formed at a 45 degree angle. The trend to higher efficiencies with the lower pressure drop is also noted. Photographs were made of the particle paths formed by the lip of blade assembly #4, Figure 21, and by blade assembly #8, Figure 22, and a comparison of the centerlines of these paths show that the curved cross section of blade assembly #8 permits the dust particles to be picked up by the drag of the dust laden air more quickly than does the angular lip of blade assembly #4. This probably indicates that there is less loss caused by eddy currents with the curved blade.

Back Wall Effect.--Runs 56 thru 68 were made to determine what effect the distance from the louver blade to the back wall would have on the efficiency of separation. Three different blades were used in these runs and the distance from the louver blade to the back wall was varied from 1.25 inches to 5.25 inches. The ratio of this distance to the louver blade opening varied from 3.26/1 to 9.76/1.

As a result of these tests no appreciable difference in the efficiency of the louver blade was noted for the various back wall locations.

During these runs it was not possible to maintain the same velocity down the louver face for each run. As a result of this velocity change the pressure drop across the louver blade opening changed from run to run even though the flow rate through the opening was the same.

Particle Size Distribution.--Samples of dust from the cleaned air were obtainable only from the runs where Microballons were used. A particle size distribution of the samples was made by the Microscopy Laboratory of the Engineering Experiment Station of the Georgia Institute of Technology and the results are shown graphically in Figures 8, 10 and 12. Microphotographs used to make the particle count are shown in Figures 7, 9 and 11.

The initial mean particle size of the Microballons was 64 microns. In the cleaned air of run 50 the mean diameter of the particles that escaped separation was 47 microns and 79 per cent of the particles were smaller than 64 microns. In the cleaned air of run 55 the mean diameter of the particles that escaped separation was 43 microns and 94 per cent were less than 64 microns.

A particle size distribution graph and a microphotograph of the Alundum dust used for the tests is shown in Figures 6 and 5 respectively.

CHAPTER VIII

CONCLUSIONS AND RECOMMENDATIONS

Conclusions.---The most important conclusion that can be drawn from this investigation is that the louver blade design that will operate with the lowest pressure drop across the opening between the louver blades will be the most efficient in separating dust particles from the dust laden air; provided, all other factors that effect the mechanism of separation remain the same. Fortunately this relationship will be most desirable in any practical dust filter since the lower pressure drop will require less power to effect the separation. The louver blade that will provide the lowest pressure drop will probably have a profile approximating that of a convergent nozzle or that of blade assembly number 8 used in this investigation.

It was found that the mass density of the dust particles had a pronounced effect on the efficiency of separation. Approximately twenty times the weight of the light particles tested, 9 pounds per cubic foot, escaped separation as did the heavy particles tested, 258 pounds per cubic foot. The effect of a change in the ratio of the velocity of the air through the louver opening to the velocity down the louver face was also more pronounced in the light particles. Although not proven experimentally the formulae of Chapter III indicate the relationship between particle density and efficiency of separation will be linear.

Although the effects of particle size on the efficiency of separation could be observed for the low density particles only it was found that the particle size did effect separation. For the low density dust it was found that particles of all sizes could be removed but that almost complete removal of particles over 80 microns in diameter was obtained with blade assembly number 8.

For the range of back wall to louver blade conditions investigated it was found that the distance from the back wall to the louver blade had no effect on the efficiency of separation. Although it was impossible to reduce the back wall to louver blade distance to a 1 to 1 ratio it is believed that in a practical dust separator the back wall effect can be safely neglected.

The efficiencies of all the blades in separating the high density Alundum dust may appear to be extremely high in comparison with air filtering methods commonly employed but this is the efficiency of one blade only and not the overall efficiency of a louver dust separator. As shown in Appendix E a louver blade with an efficiency of 99 per cent will give an overall efficiency of 97.87 per cent if 10 per cent blowdown is allowed and if less blowdown is allowed the overall efficiency will be lower than this. However, if the efficiency of the individual blade can be made greater than 99 per cent then a high overall efficiency with low blowdown and very little pressure loss through the separator can be attained.

Recommendations.--The recommendations for further investigations of the louver type dust separator are based on the conclusion that the blade shape that will cause the lowest pressure drop across the louver opening will be the most efficient in removing dust particles from the air. It is felt that by continued experimentation with the individual louver blade shapes and proportions that a practical blade that gives maximum performance could be developed. Certain elements of the blade design, such as the effect of the angle from the trailing edge of one blade to the leading edge of the next, have not been investigated and should be considered.

If an apparatus similar to that used in this investigation were employed a more suitable means of determining the amount of dust in the cleaned air should be devised. A change in the blowdown bag that would permit continuous injection of dust without increasing the blowdown resistance would permit longer runs and thus reduce the percentage error in weighing the cleaned air filter bags. A very accurate method of sampling and weighing the dust in the cleaned air would also accomplish this.

Once a blade shape has been selected it is believed that the construction of a full scale air filter would permit the incorporation and study of the various conclusions that have been formed concerning the mechanism of separation. The filter should be conical in section with each louver blade formed into a circle, or for ease of construction a hexagon. The design should be such that the velocity of the dust laden air down the louver face is constant from inlet to blowdown. The average velocity through each of the louver openings should be the same and the ratio of the velocity of the air through the louver openings to the velocity of the air down the louver face should be approximately 1 to 1. The blowdown should not be less than 6 per cent of the inlet air.

APPENDIX A

LIST OF SYMBOLS

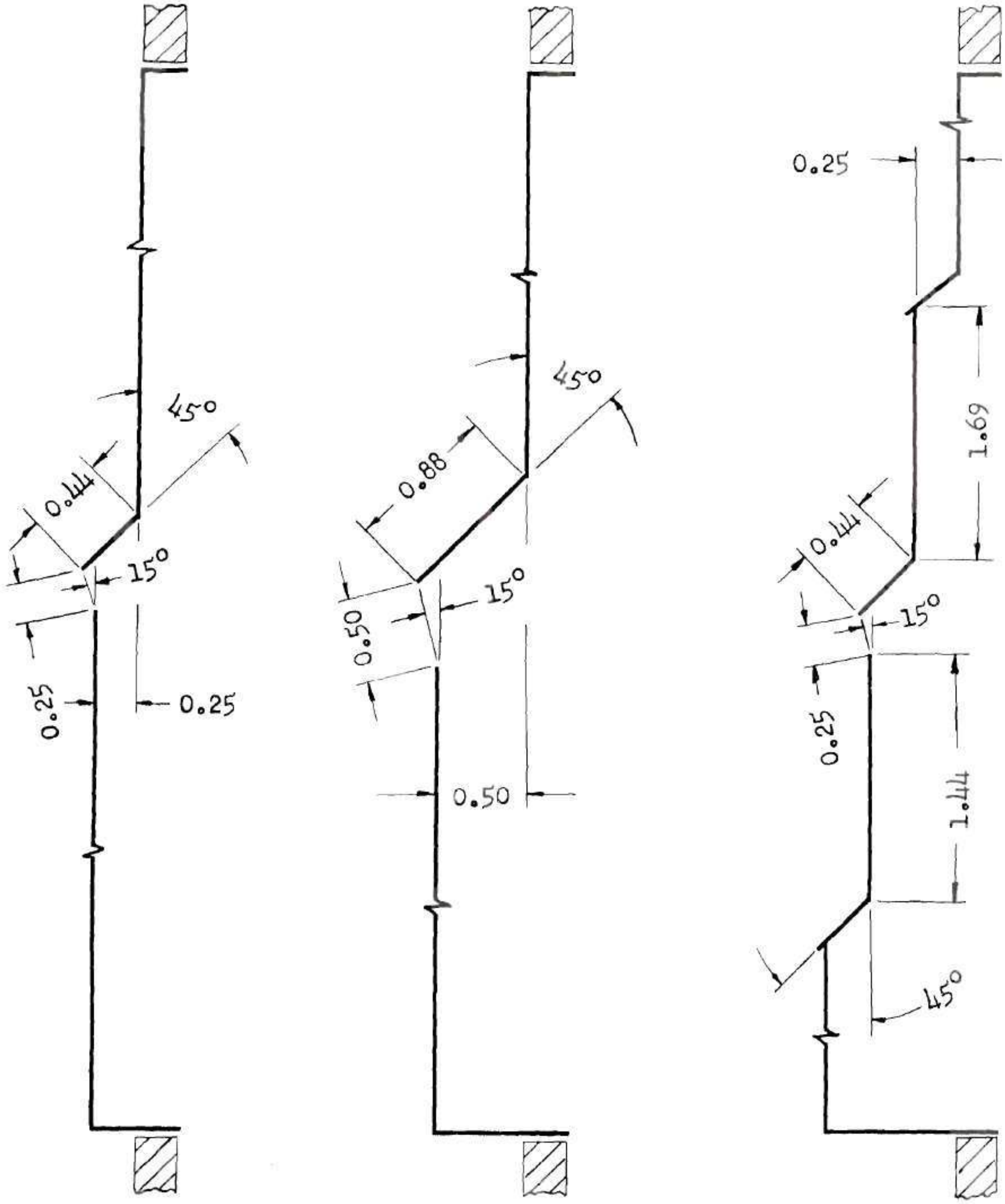
LIST OF SYMBOLS

A_2	Cross sectional area of dust laden air passage at louver blade
A_{i2}	Throat area of dust injector nozzle
C	Coefficient of discharge, inlet air orifice
C_i	Coefficient of discharge, dust injector nozzle
c_2	Air - dust concentration before louver blade
c_3	Air - dust concentration of cleaned air
D	Diameter of dust particle
D_1	Inlet air pipe diameter
D_2	Inlet air orifice diameter
D_{i2}	Diameter of dust injector nozzle throat
G_2	Rate of dust flow before louver blade
G_3	Rate of dust flow in cleaned air
h_1	Differential pressure, inlet air orifice
h_{s1}	Upstream static pressure, inlet air orifice
h_2	Differential pressure, across louver blade
h_{s2}	Static pressure, inlet air side of louver blade
h_{sRo}	Upstream static pressure, cleaned air rotameter
K	Flow coefficient, inlet air orifice
K_p	Rotameter pressure correction factor
K_t	Rotameter temperature correction factor
P_c	Rotameter calibration pressure
P_{i1}	Upstream air pressure, dust injector nozzle
R	Gas constant for air

R_o	Cleaned air rotameter reading, uncorrected
S_2	Distance from louver blade to back wall
T_1	Upstream temperature, inlet air orifice
T_2	Air temperature, inlet air side of louver blade
T_c	Rotameter calibration temperature
T_{i1}	Upstream air temperature, dust injector nozzle
T_{Ro}	Upstream air temperature, cleaned air rotameter
V_2	Average velocity, dust laden air at louver blade
V_x	Air velocity parallel to inlet air flow
V_y	Air velocity normal to inlet air flow
V_{yc}	Dust particle velocity normal to inlet air flow
W_1	Mass of air flow, inlet air orifice
W_2	Mass of air flow, dust laden air at louver blade
W_3	Mass of air flow, cleaned air rotameter
W_i	Mass of air flow, dust injector nozzle
x	Coordinate parallel to inlet air flow, origin at blade tip
y	Coordinate normal to inlet air flow, origin at blade tip
β	D_2/D_1
ρ_1	Upstream air density, inlet air orifice
ρ_3	Upstream air density, rotameter
ρ_a	Density of air
ρ_p	Density of dust particle

APPENDIX B

FIGURES



Blade Assembly #1 Blade Assembly #2 Blade Assembly #3

FIGURE 1

LOUVER BLADE PROFILES

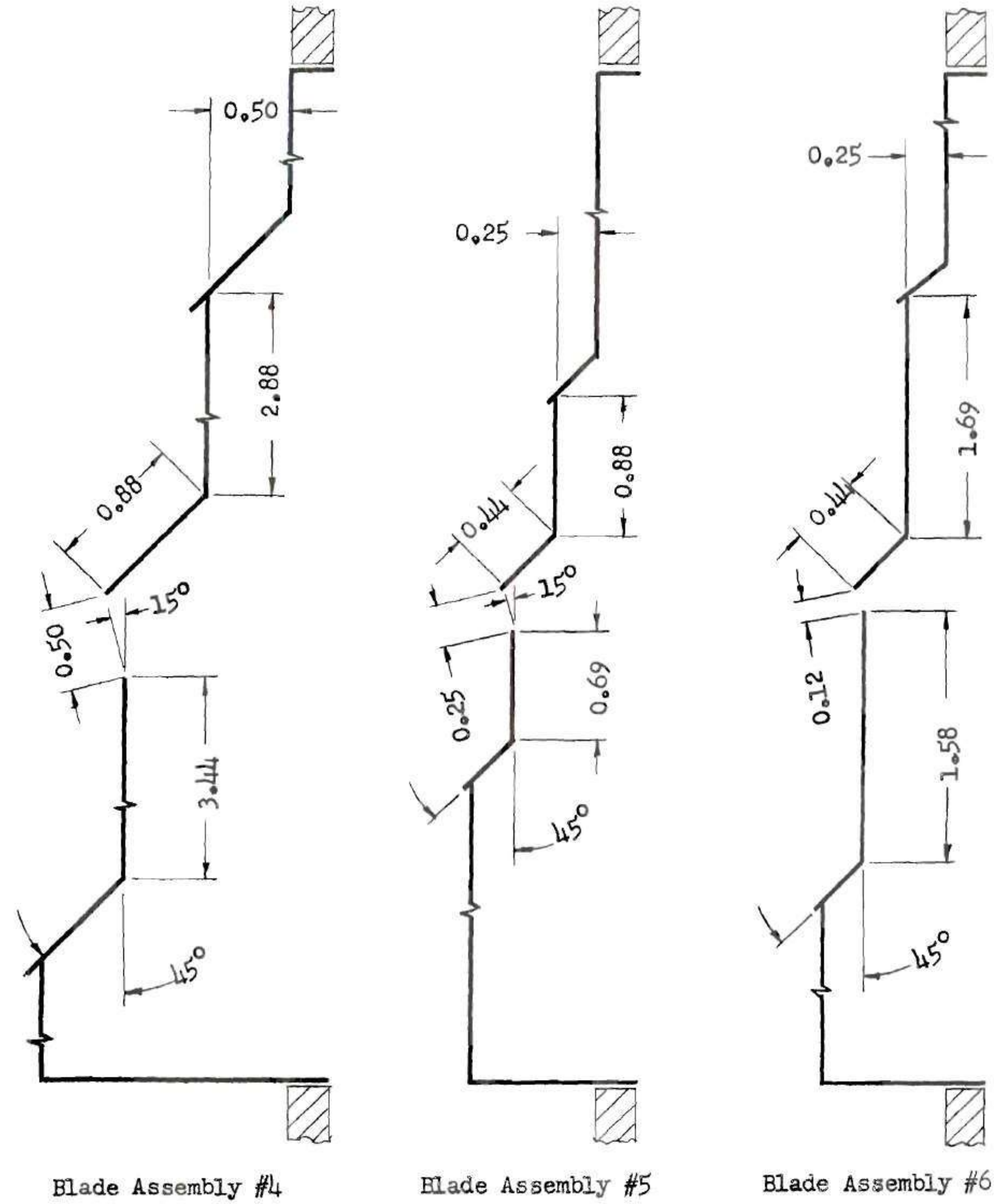
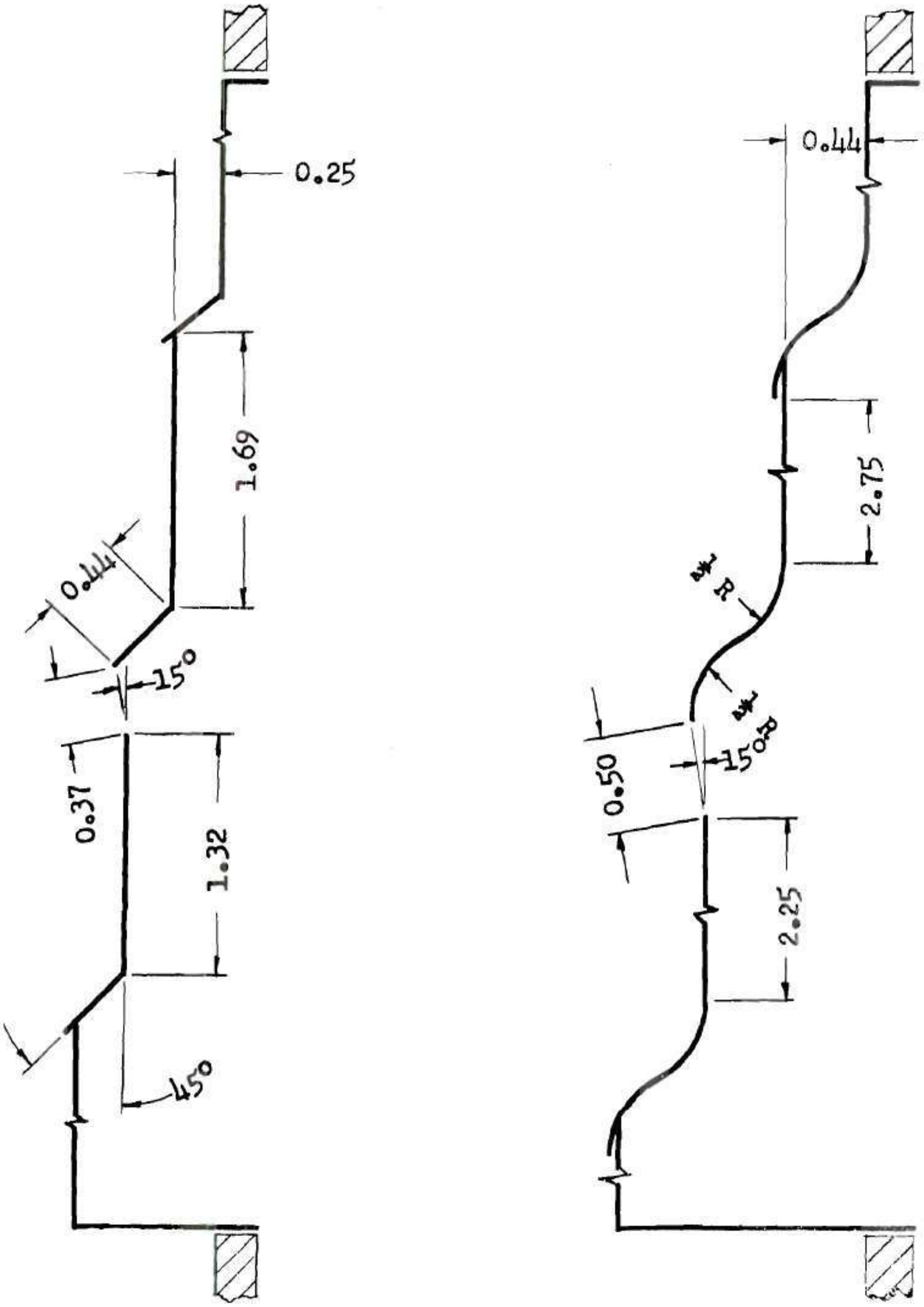


FIGURE 2

LOUVER BLADE PROFILES



Blade Assembly #7

Blade Assembly #8

FIGURE 3

LOUVER BLADE PROFILES

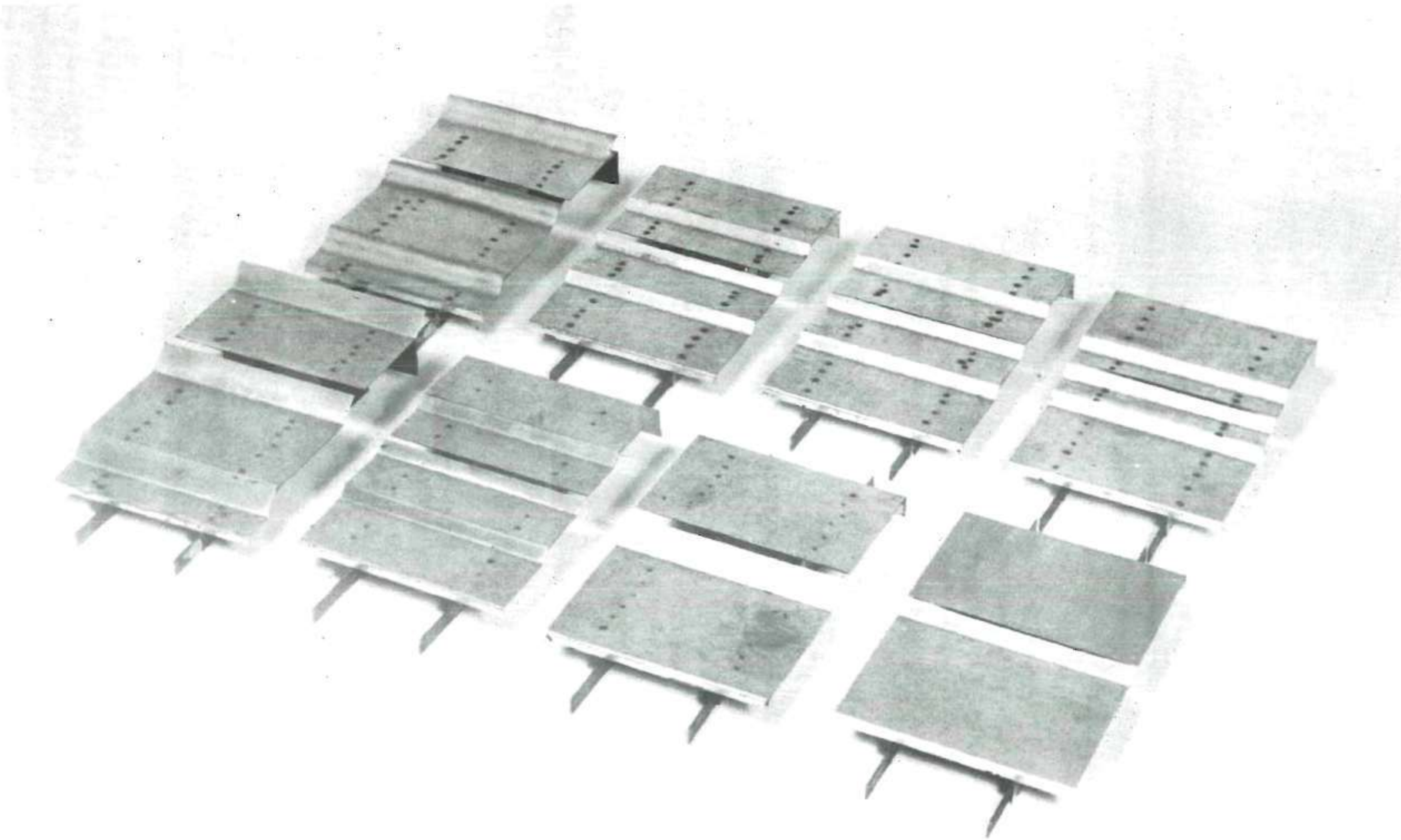


FIGURE 4

PHOTOGRAPH OF LOUVER BLADE TEST ASSEMBLIES

FIGURE 5

MICROPHOTOGRAPH OF ALUNDUM 240 GRIT ABRASIVE PARTICLES (X 100)

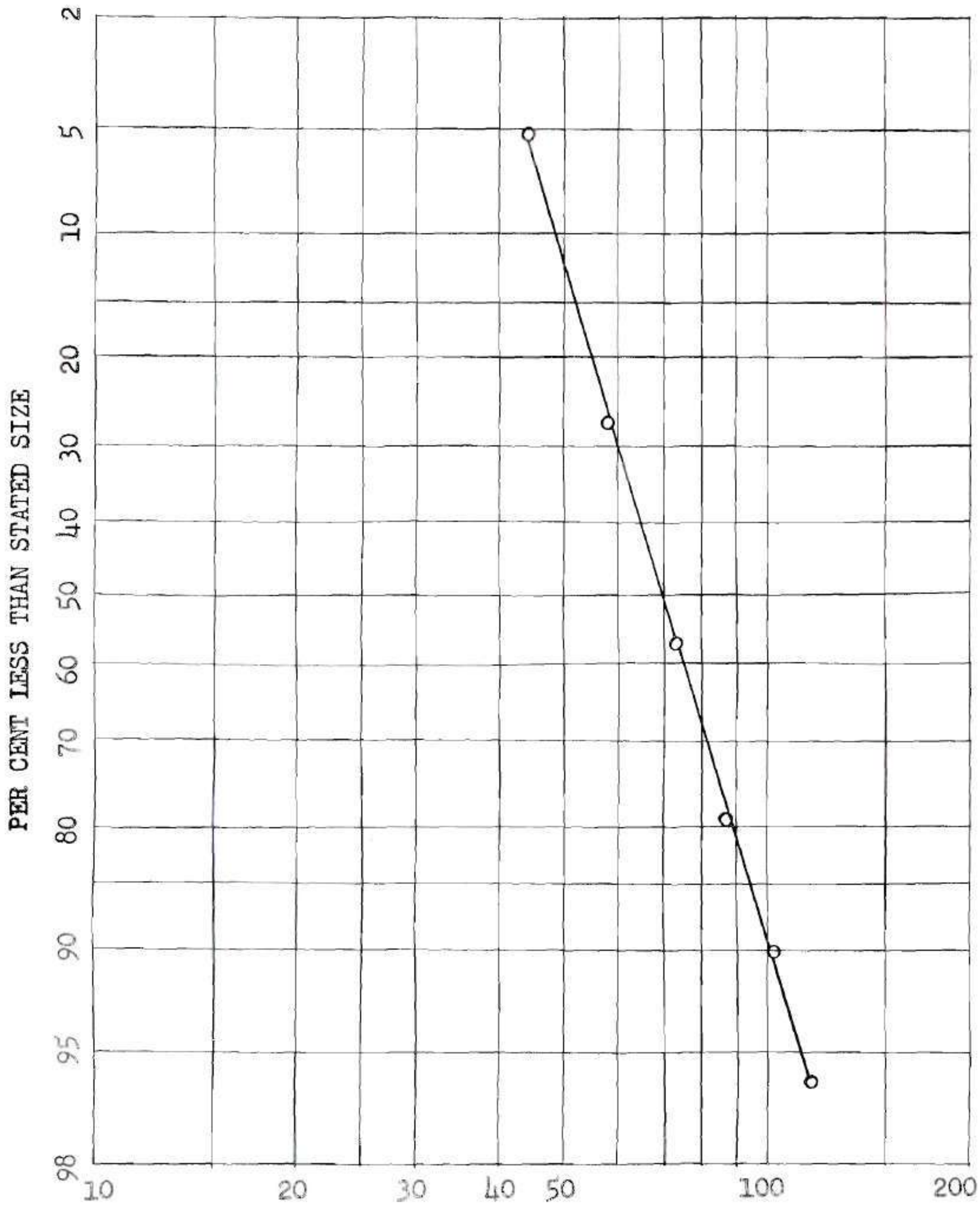


FIGURE 6

PARTICLE DISTRIBUTION OF ALUNDUM 240 GRIT ABRASIVE
AS INJECTED

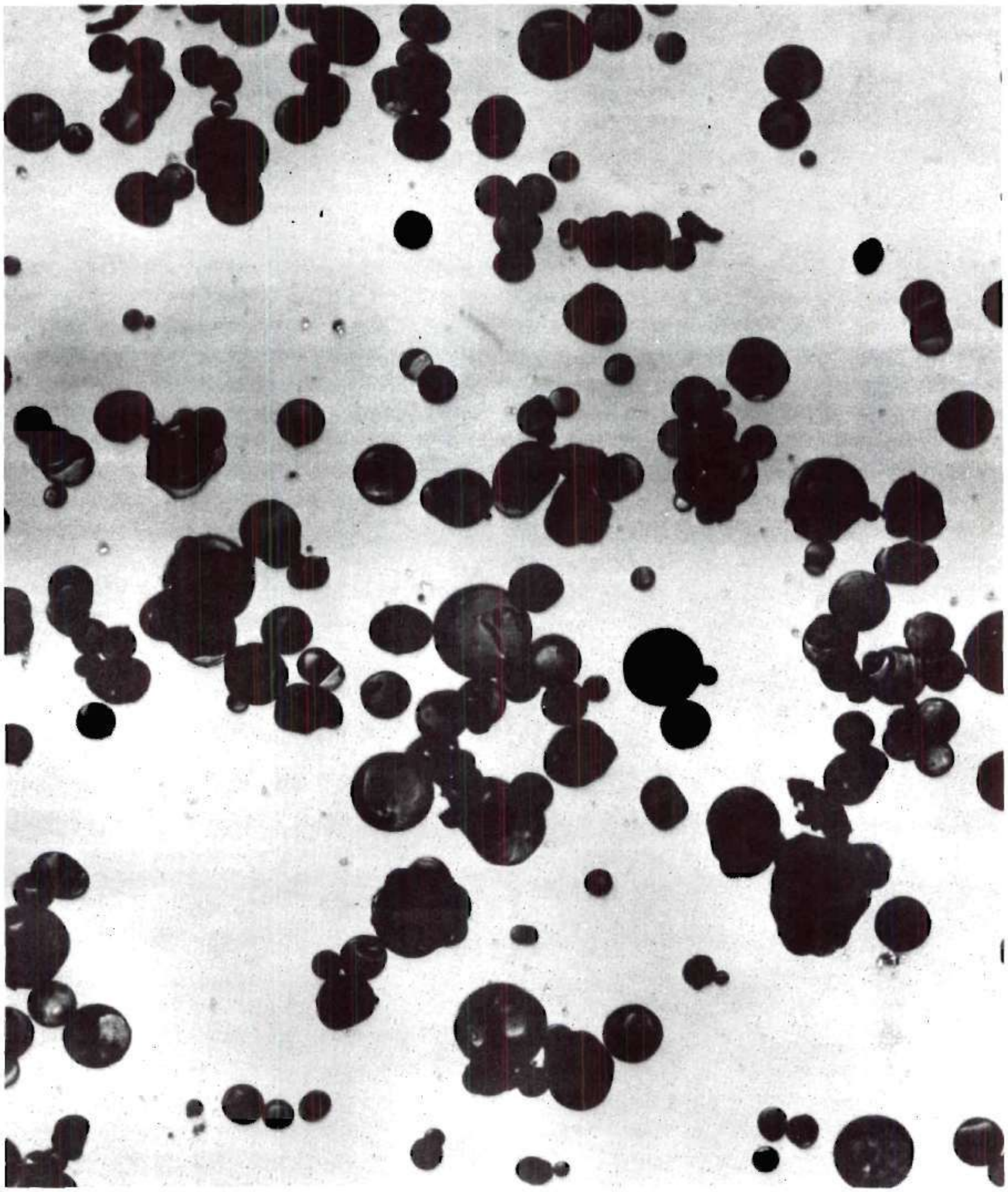


FIGURE 7

MICROPHOTOGRAPH OF MICROBALLON PARTICLES (X 100)

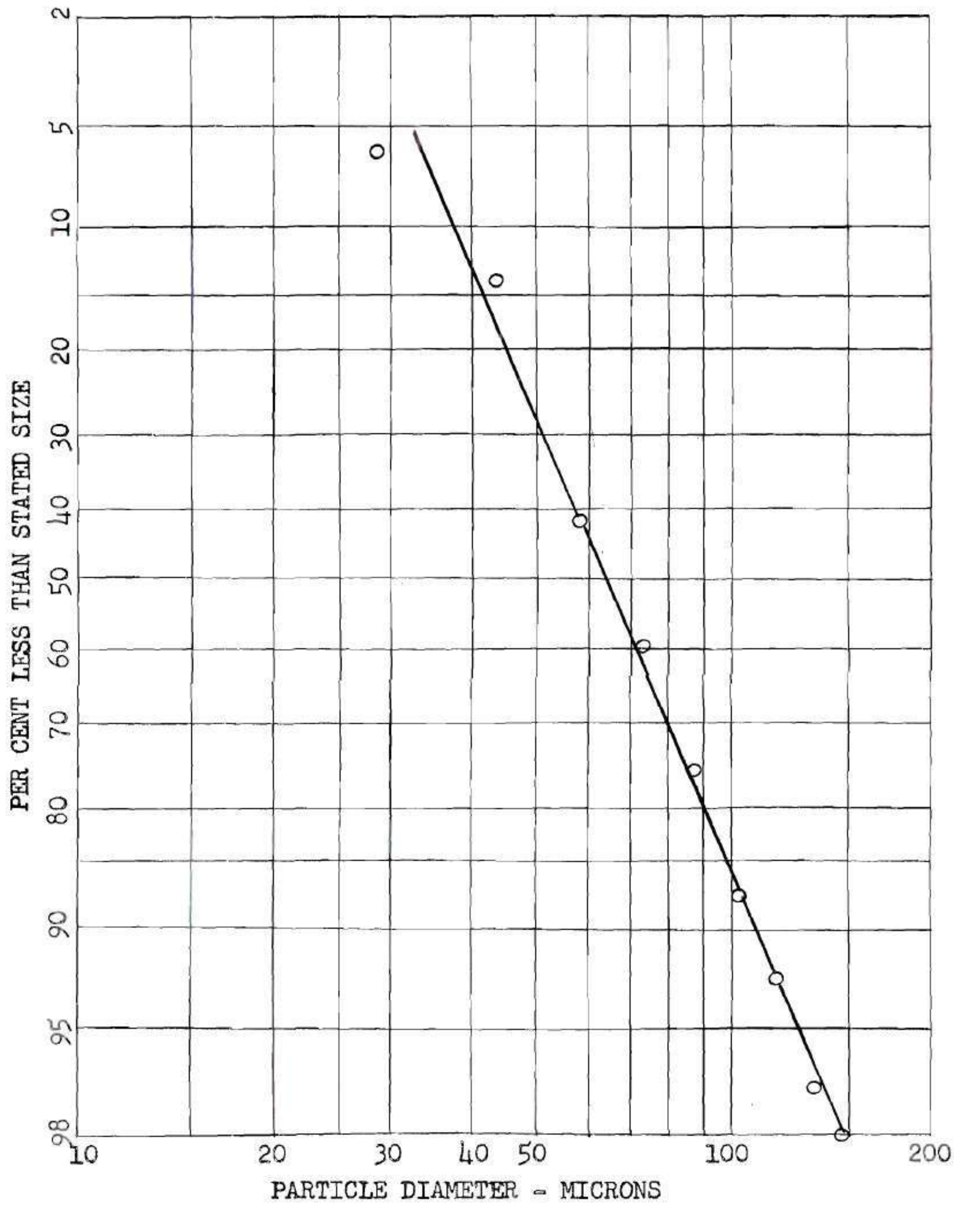


FIGURE 8

PARTICLE DISTRIBUTION OF MICROBALLONS AS INJECTED

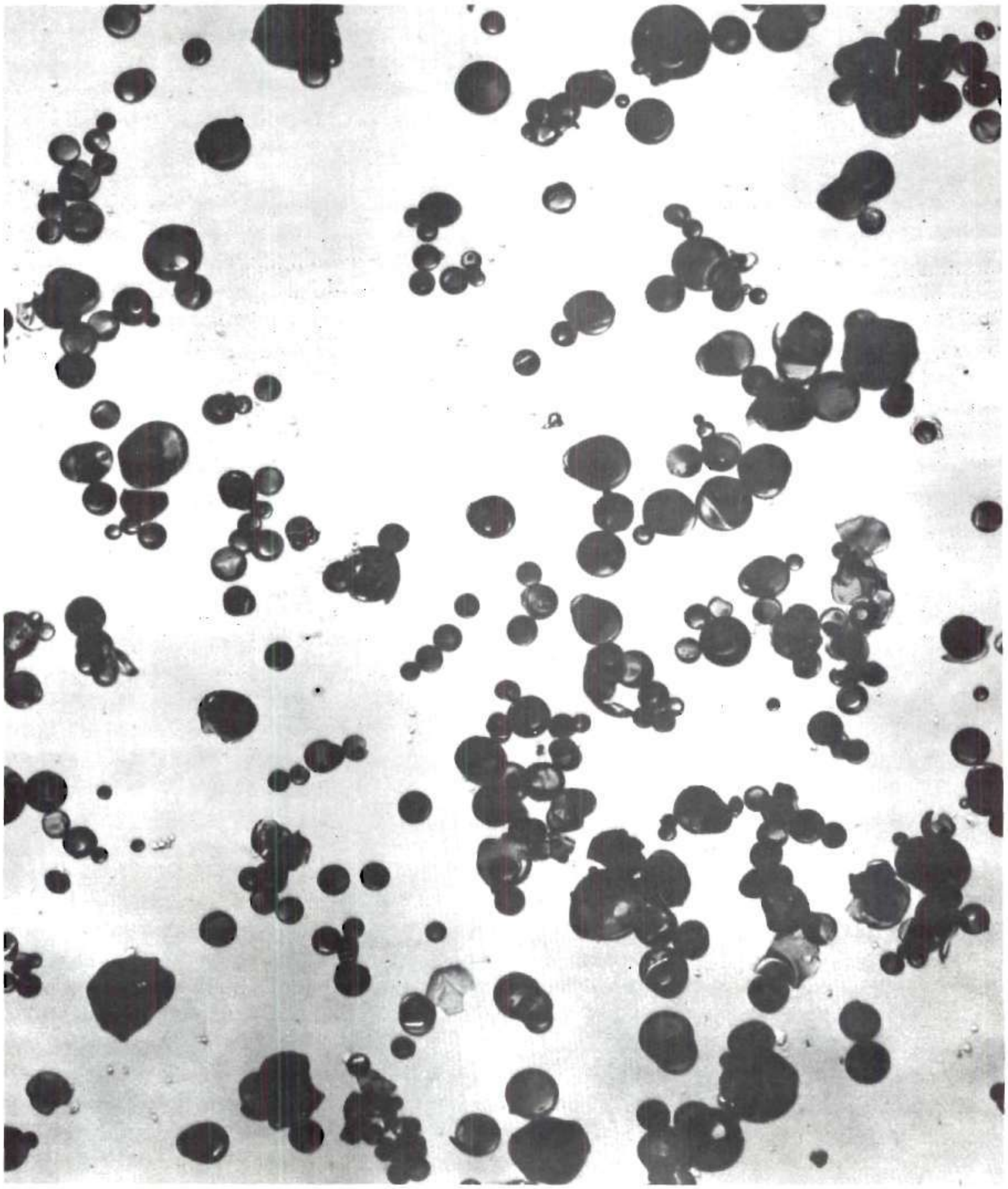


FIGURE 9

MICROPHOTOGRAPHS OF MICROBALLONS IN CLEANED AIR RUN NUMBER 50 (X 100)

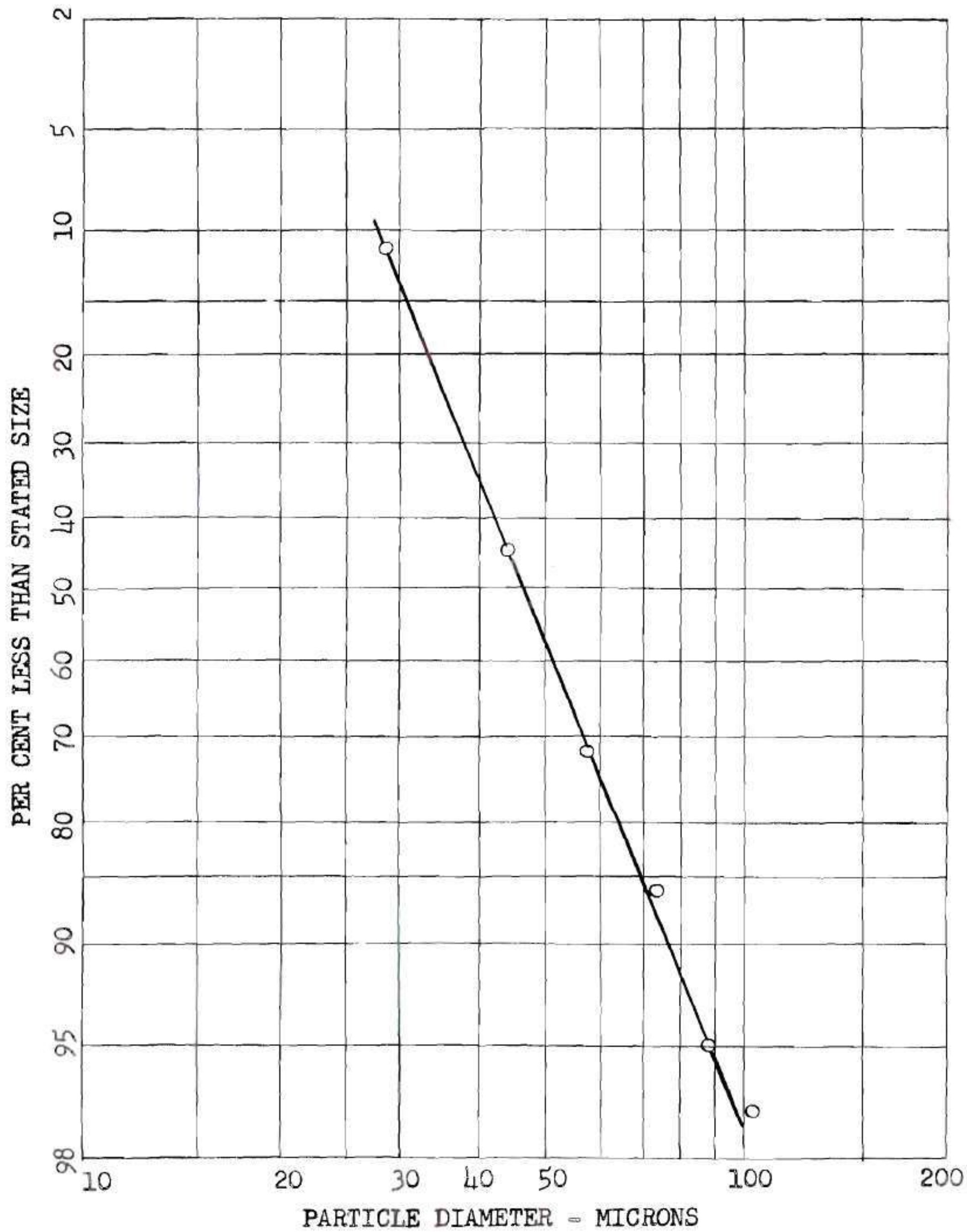


FIGURE 10

PARTICLE DISTRUBITION OF MICROBALLONS IN CLEANED AIR
RUN NUMBER 50

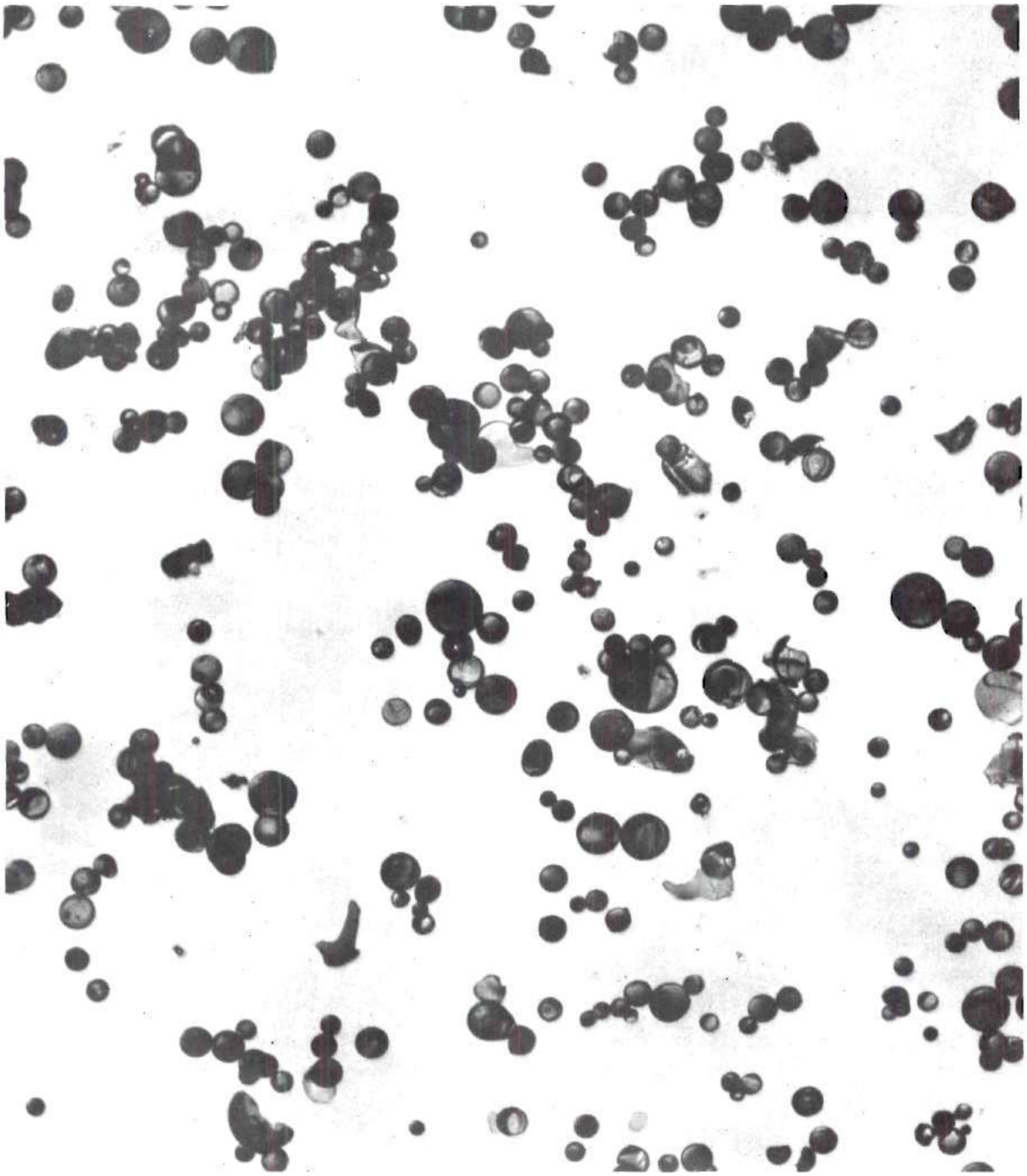


FIGURE 11

MICROPHOTOGRAPHS OF MICROBALLONS IN CLEANED AIR RUN NUMBER 55 (X 100)

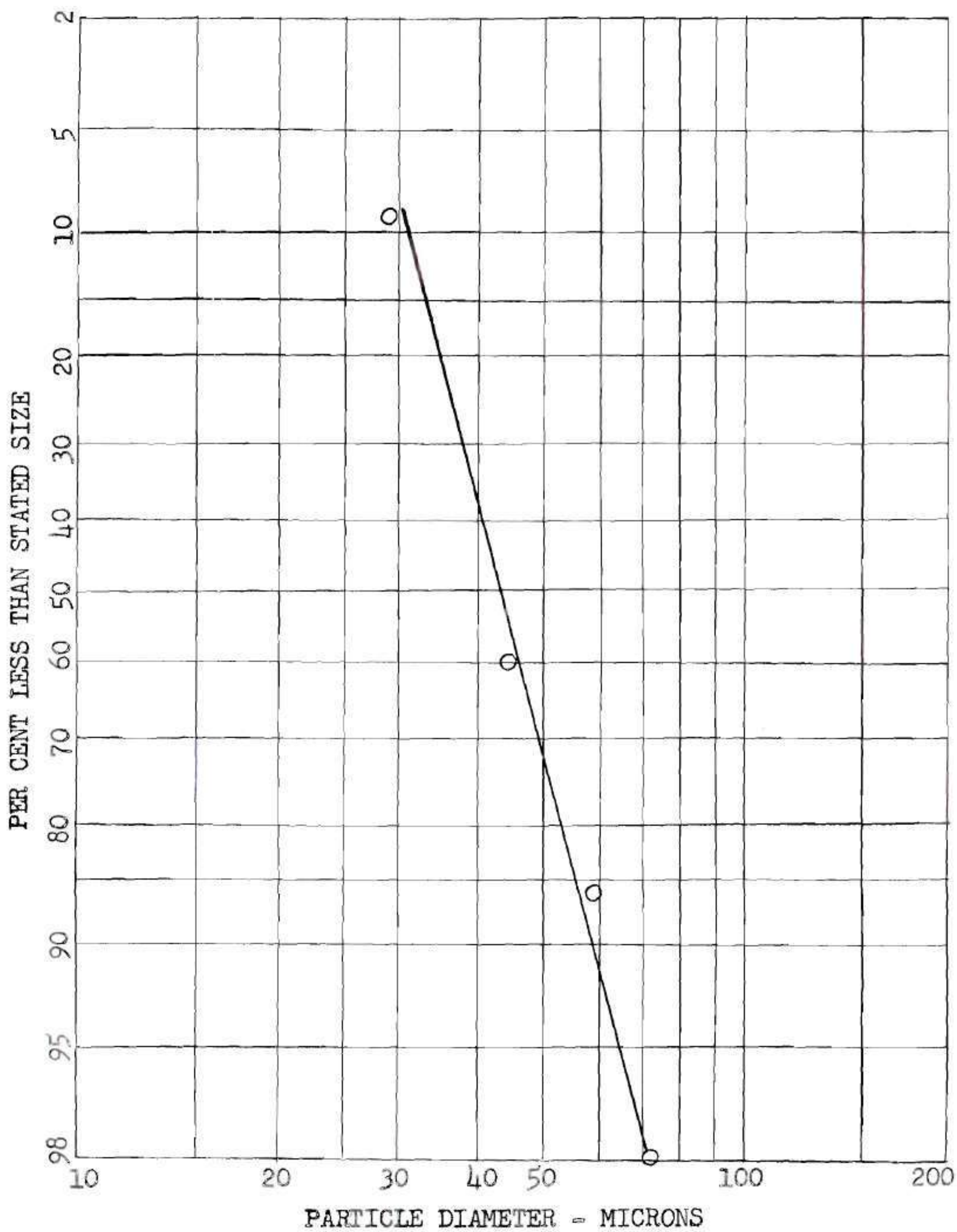
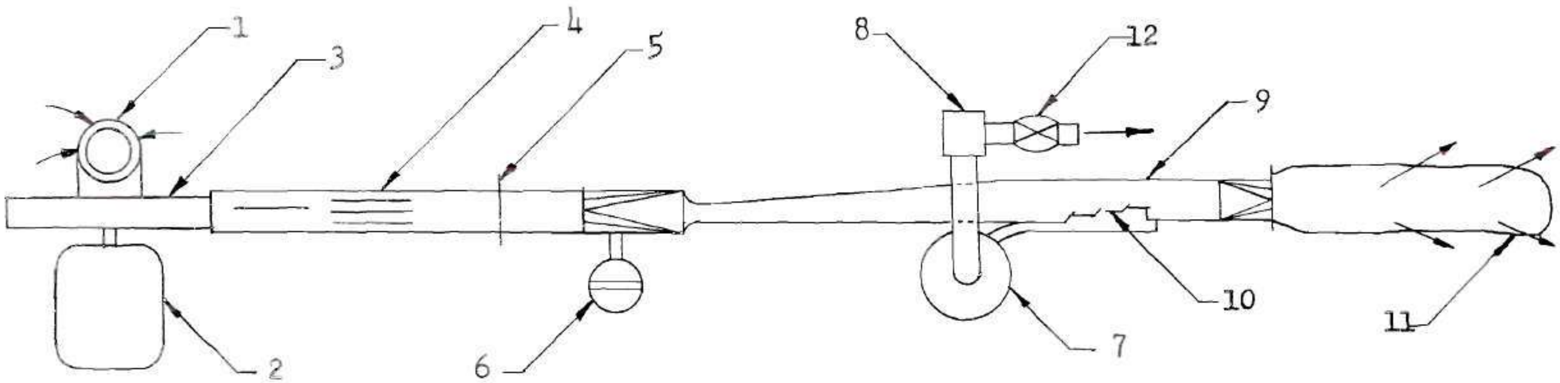


FIGURE 12

PARTICLE DISTRIBUTION OF MICROBALLONS IN CLEANED AIR
RUN NUMBER 55



1. Inlet valve
2. 15 HP motor
3. Pressure fan
4. Straightening vane
5. Inlet orifice
6. Dust feeder
7. Cleaned air filter
8. Rotameter
9. Movable wall
10. Test blade ass'y
11. Blow-down bag
12. Control valve

FIGURE 13

SKETCH OF TEST APPARATUS

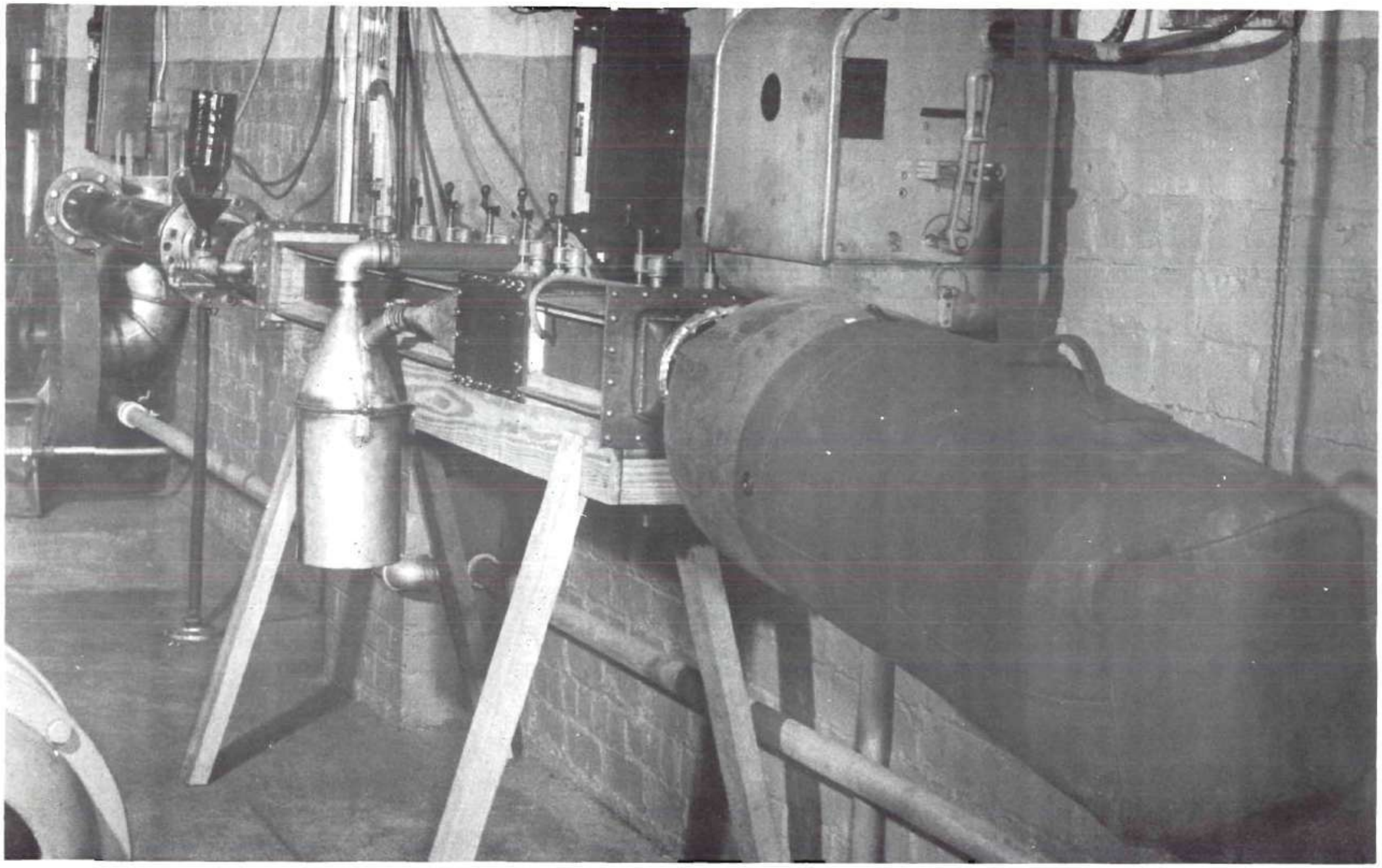


FIGURE 14

PHOTOGRAPH OF TEST APPARATUS

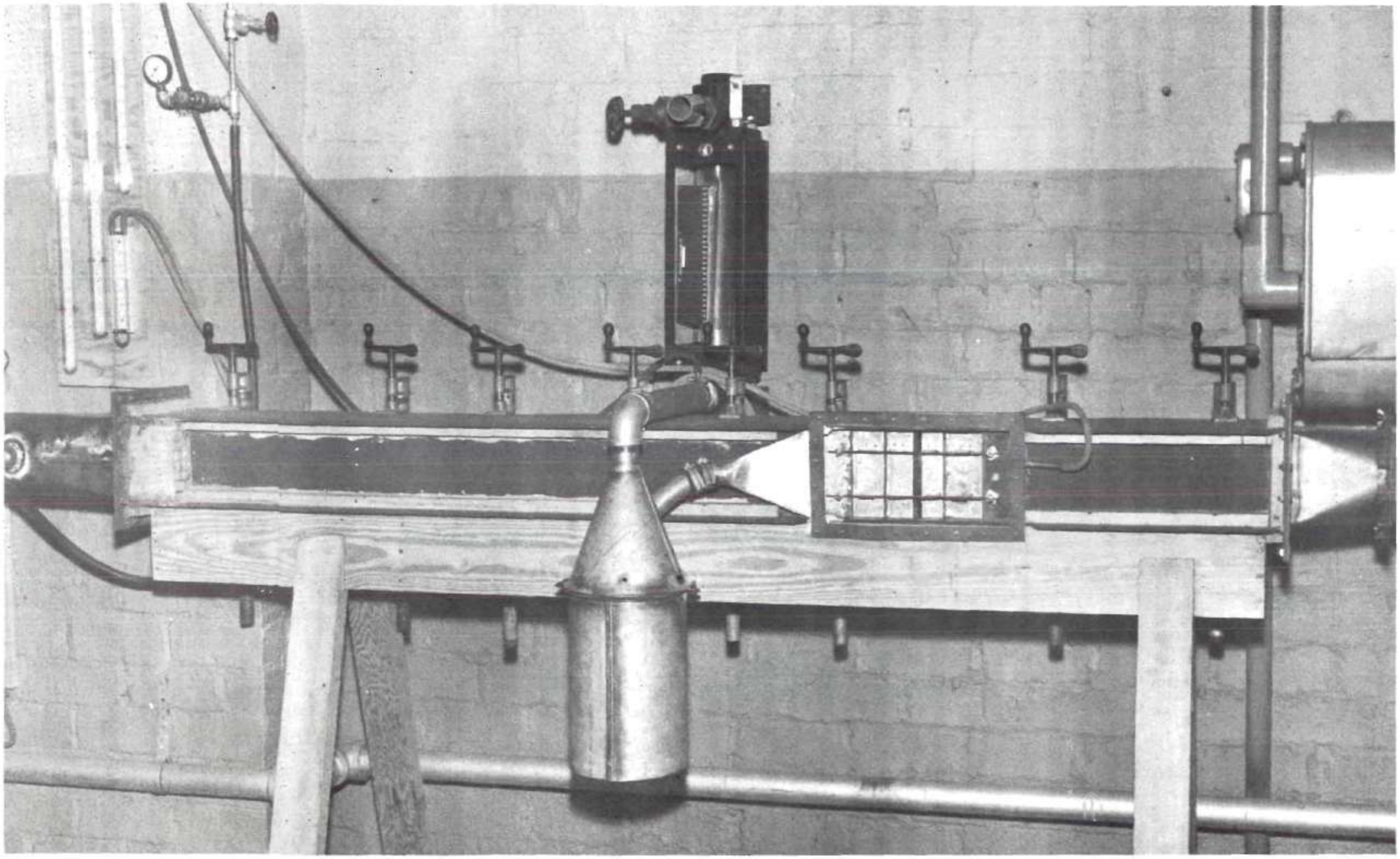


FIGURE 15

PHOTOGRAPH OF LOUVER BLADE ASSEMBLY IN TEST APPARATUS

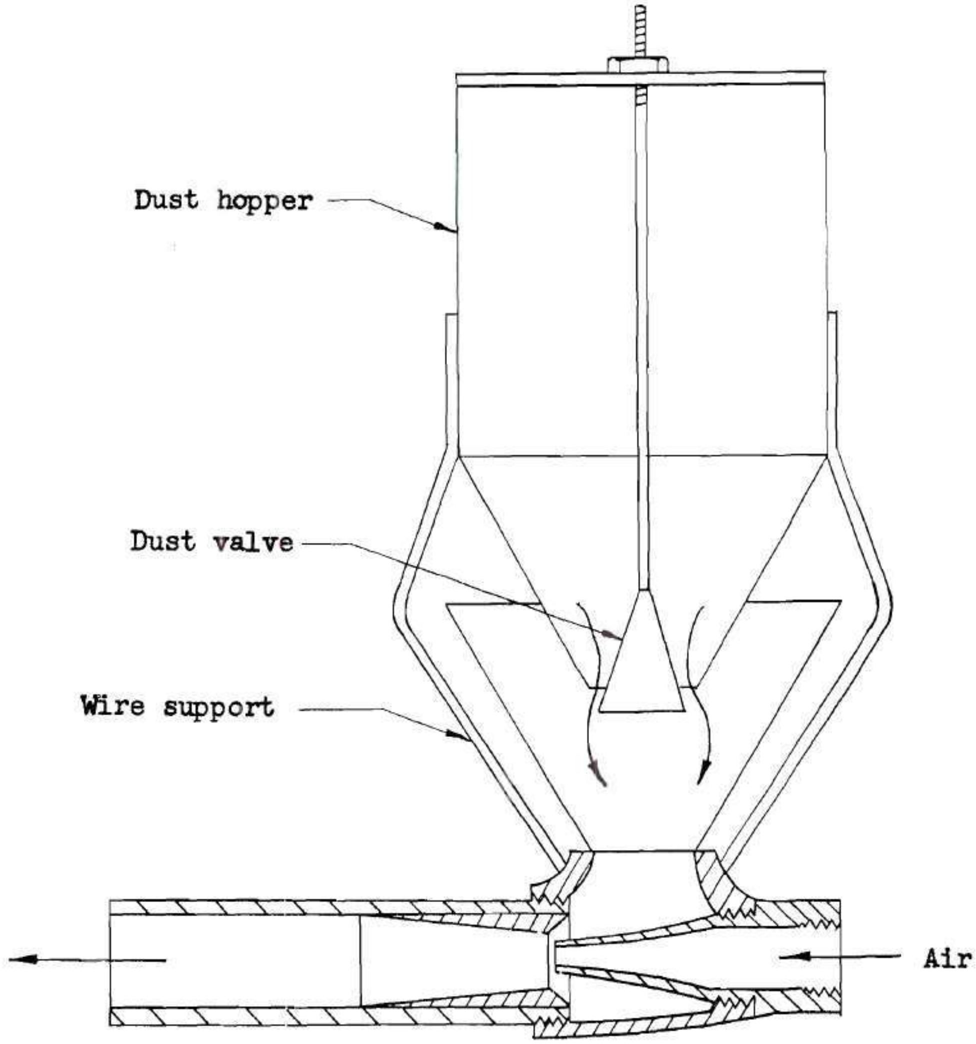


FIGURE 16

SKETCH OF DUST FEEDER

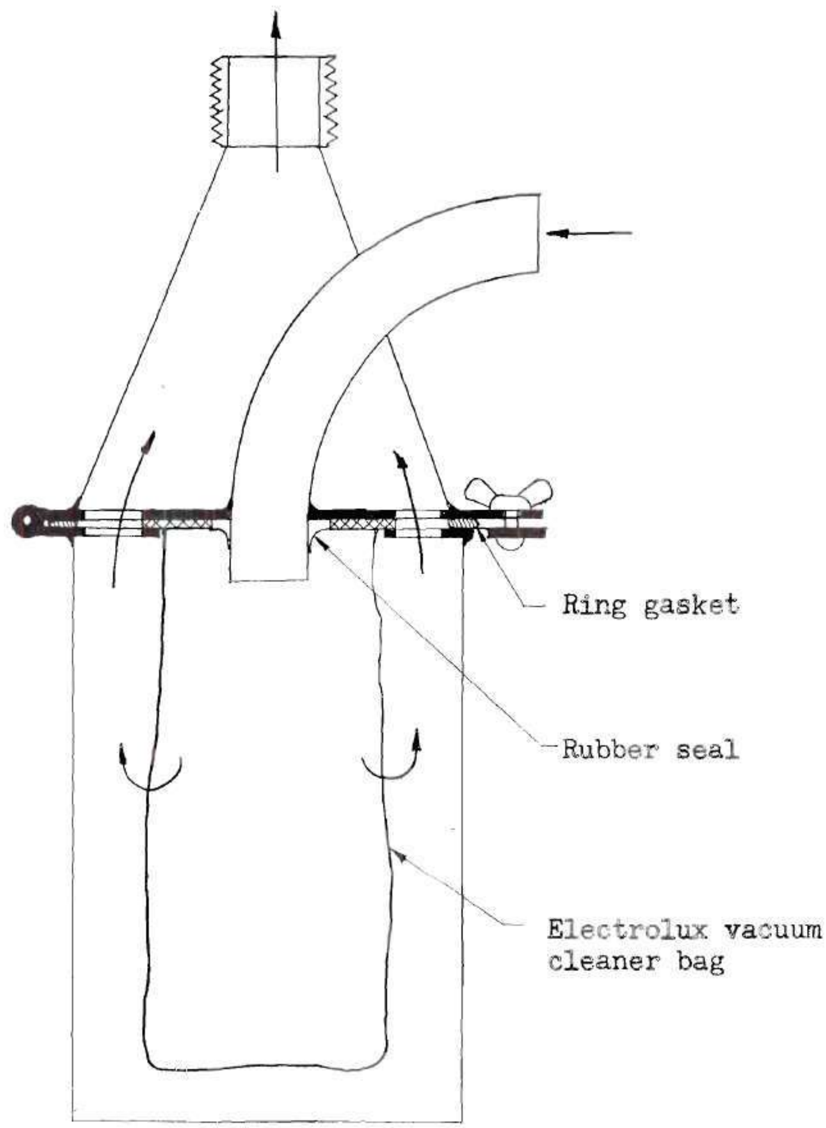


FIGURE 17

SKETCH OF CLEANED AIR FILTER

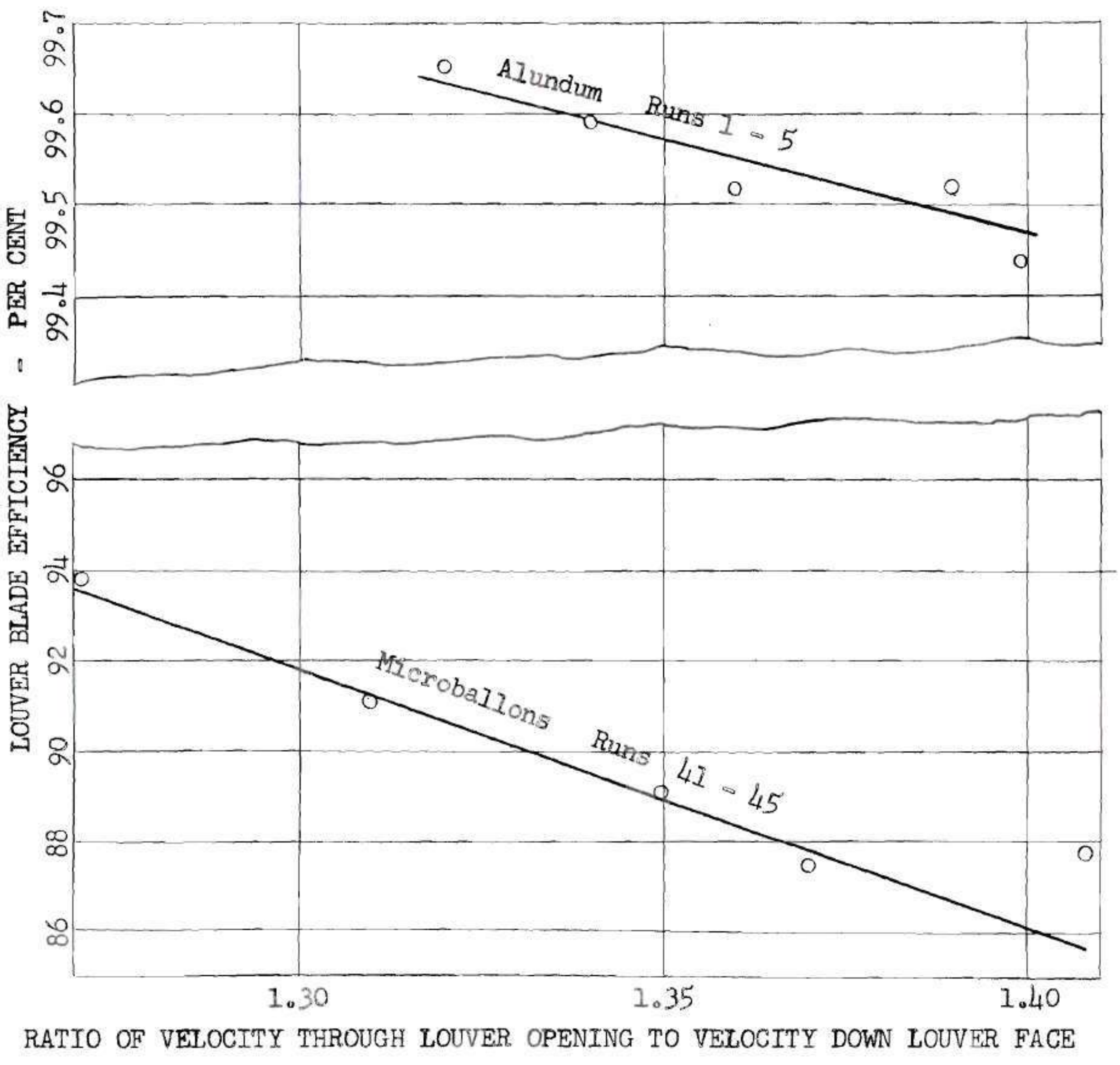


FIGURE 18

EFFECT OF VELOCITY RATIO ON LOUVER BLADE EFFICIENCY
LOUVER BLADE ASSEMBLY NUMBER 1

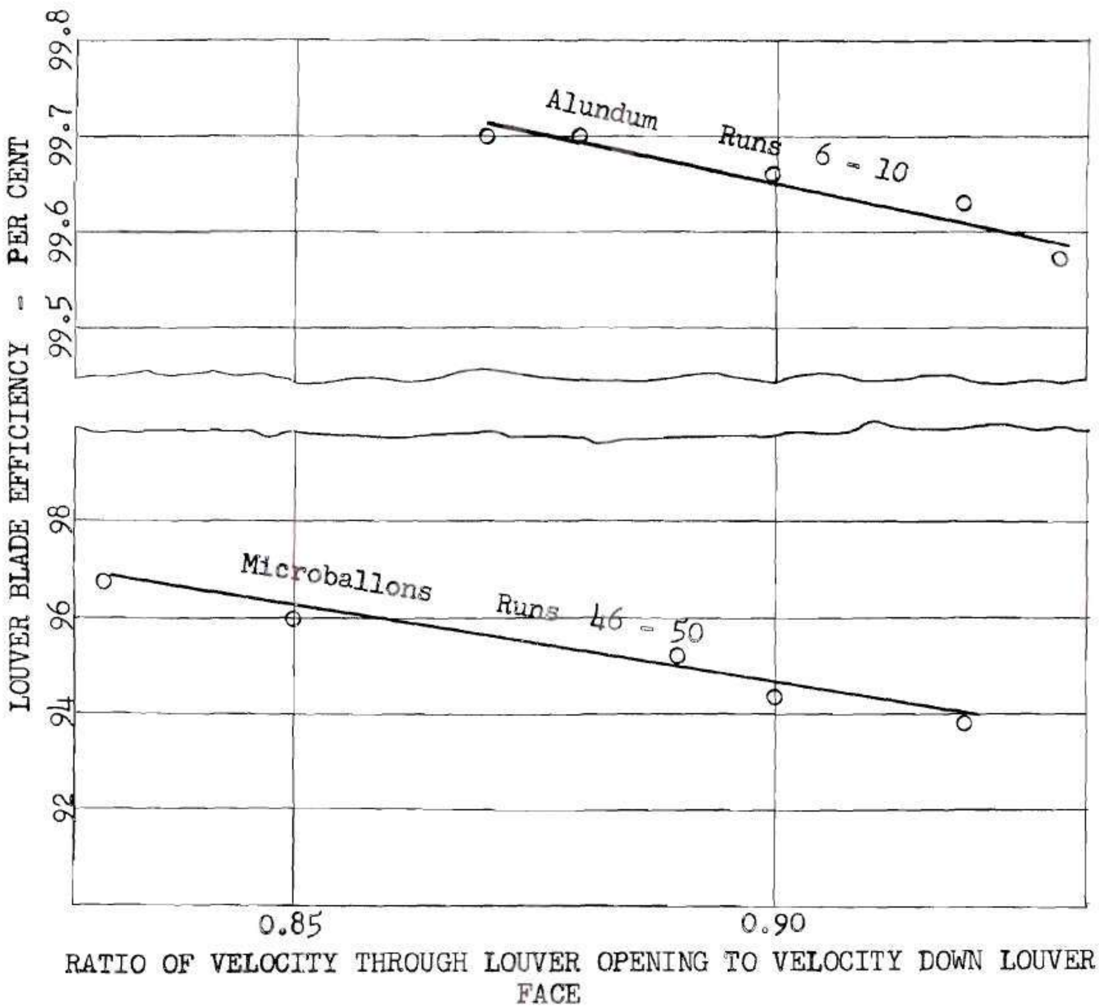


FIGURE 19

EFFECT OF VELOCITY RATIO ON LOUVER BLADE EFFICIENCY
LOUVER BLADE ASSEMBLY NUMBER 2

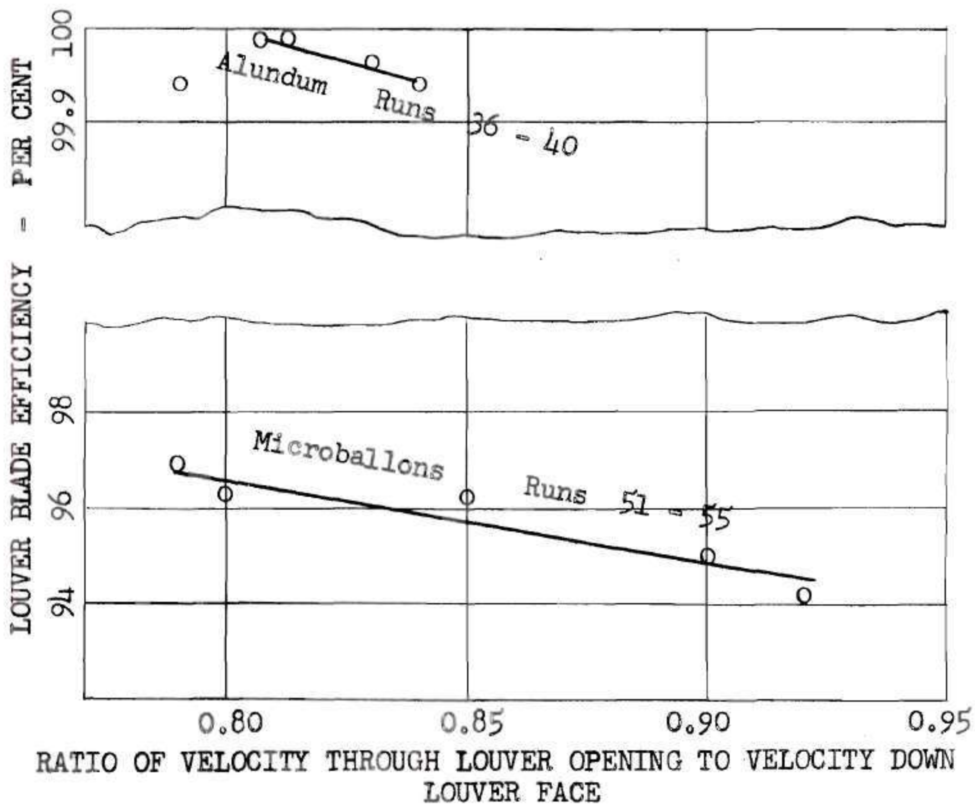


FIGURE 20

EFFECT OF VELOCITY RATIO ON LOUVER BLADE EFFICIENCY
LOUVER BLADE ASSEMBLY NUMBER 8

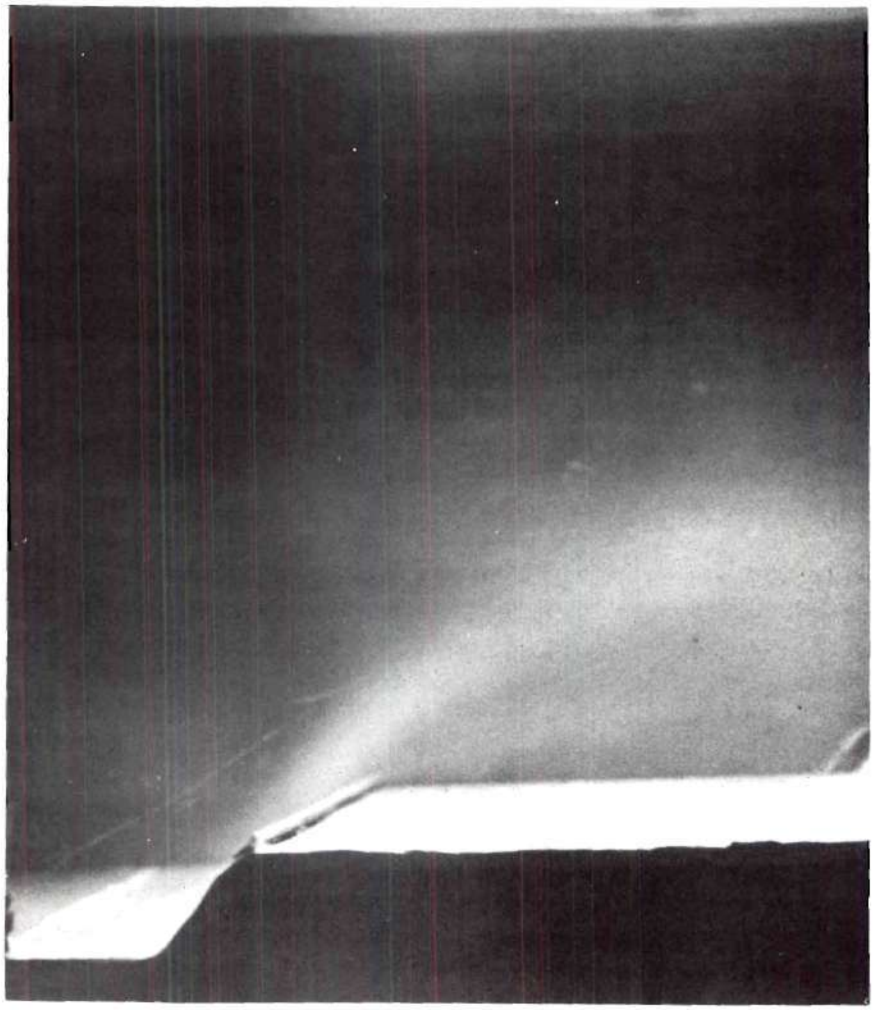


FIGURE 21

PHOTOGRAPH OF DUST PARTICLE PATHS - LOUVER BLADE ASSEMBLY #4

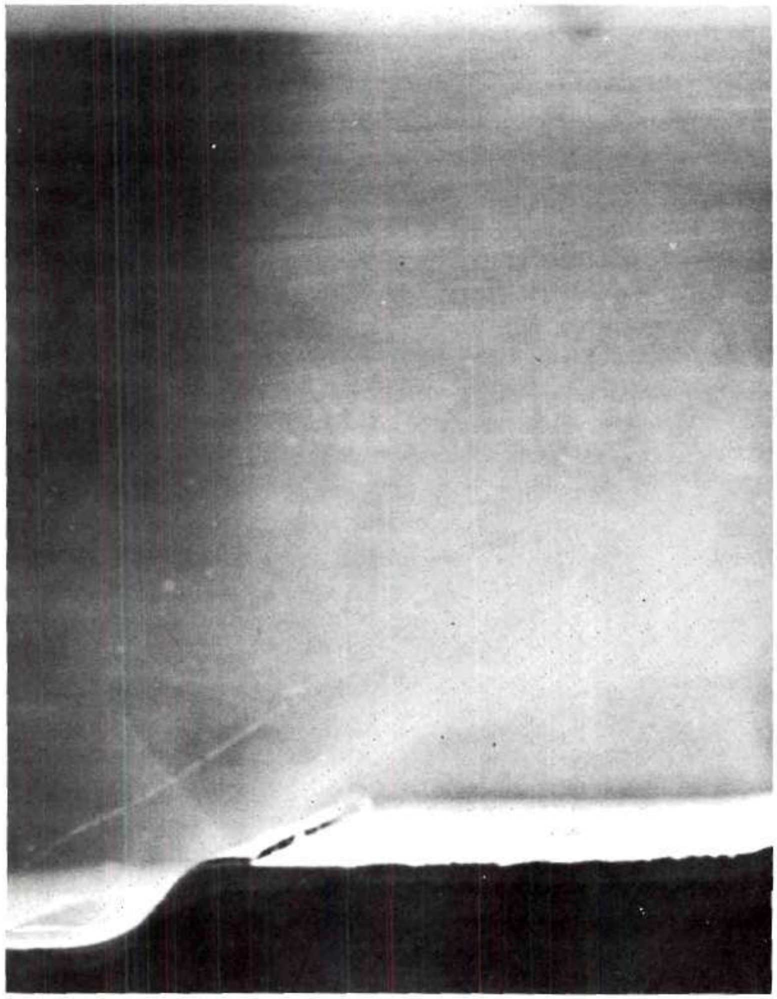


FIGURE 22

PHOTOGRAPH OF DUST PARTICLE PATHS - LOUVER BLADE ASSEMBLY #8

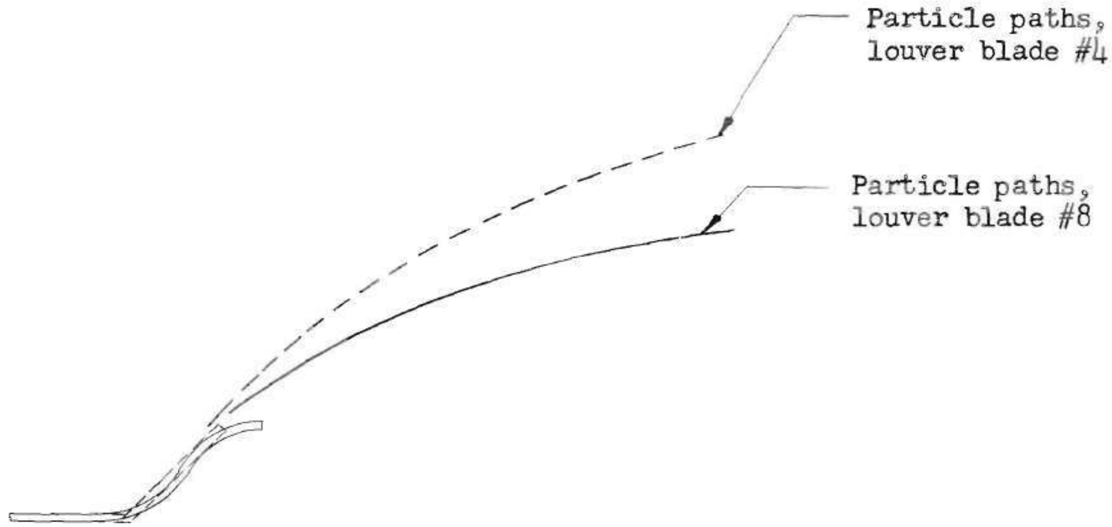
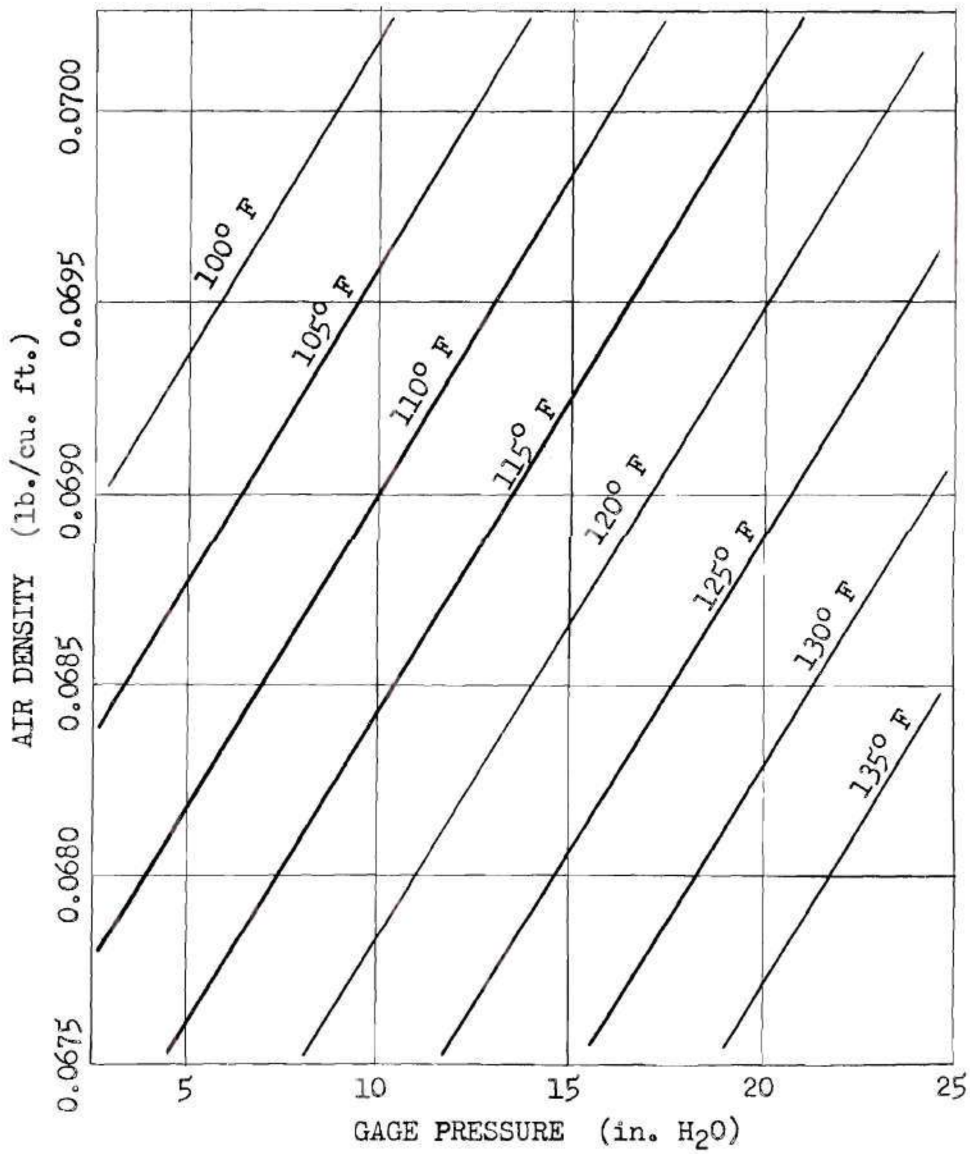


FIGURE 23

COMPARISON OF PARTICLE PATHS FOR
LOUVER BLADES #4 AND #8



For barometric pressure of 28.90 in. Hg. A 0.1 inch change in barometric pressure = 1.36 in. H_2O change in gage pressure.

FIGURE 24

AIR DENSITY CHART

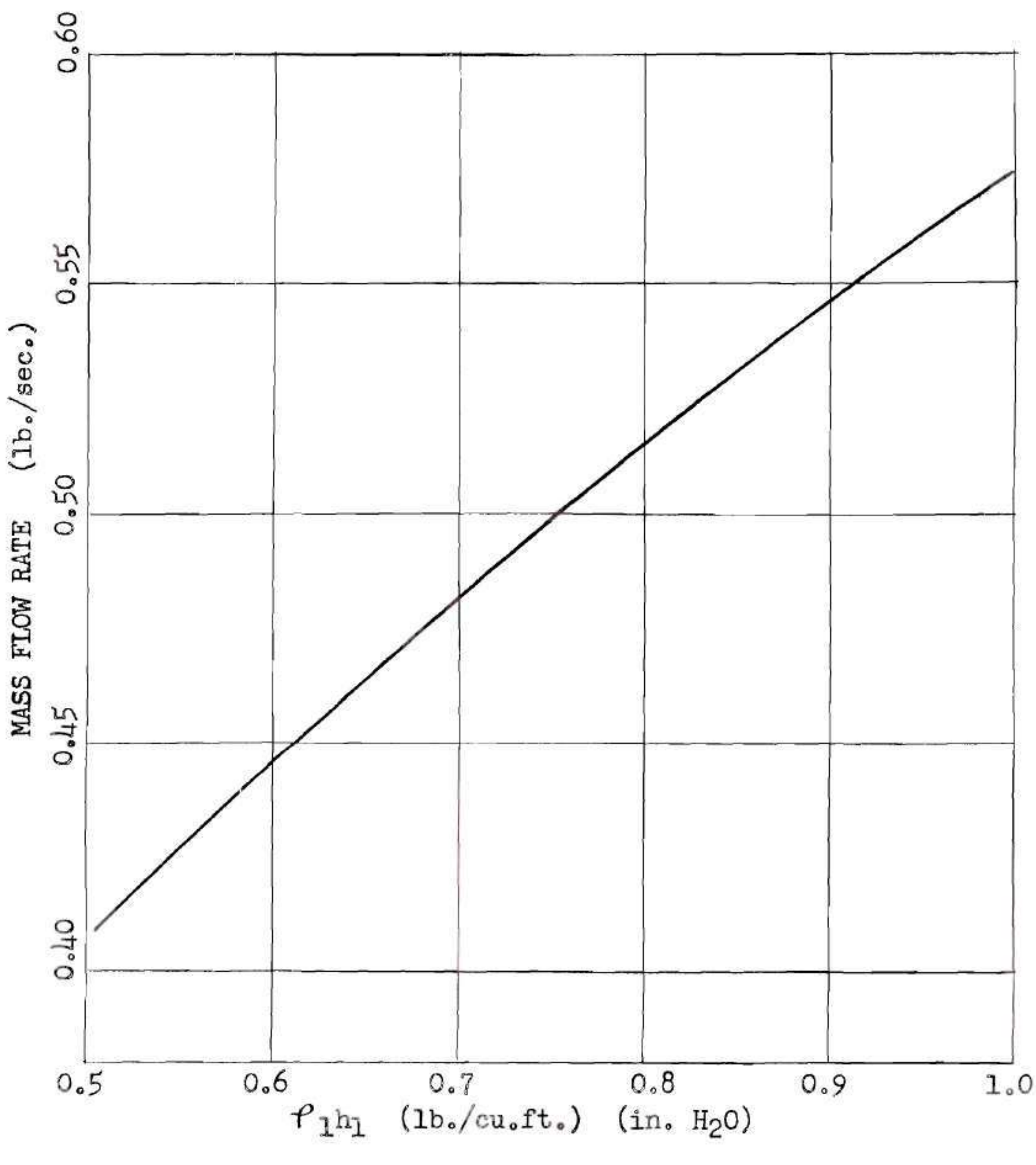


FIGURE 25

INLET ORIFICE FLOW RATE

APPENDIX C

EXPERIMENTAL RESULTS

Table 1. Air Flow Data

Run	h_1* (in.H_2O)	h_{s1} (in.H_2O)	h_2 (in.H_2O)	h_{s2} (in.H_2O)	h_{sRo} (in.H_2O)	R_o (cfm)	T_1 (F)	T_2 (F)	T_{Ro} (F)
	Blade Assembly #1, Alundum 240 Grit Dust, Barometer 28.96 in. Hg.								
1	14.7	19.5	2.8	9.0	3.9	34.8	121	112	100
2	14.0	19.7	2.8	9.4	4.7	34.8	124	115	103
3	13.7	19.9	2.8	10.0	5.3	34.8	125	115	104
4	13.2	20.2	2.8	10.5	5.7	34.8	125	115	104
5	13.0	20.4	2.8	10.8	6.1	34.8	125	115	104
	Blade Assembly #2, Alundum 240 Grit Dust, Barometer 28.86 in. Hg.								
6	13.1	18.3	1.7	9.5	5.7	45.5	124	115	106
7	12.3	18.6	1.7	10.4	5.8	45.5	125	115	106
8	12.1	19.3	1.7	10.9	6.2	45.5	125	116	107
9	11.7	20.1	1.7	11.4	6.6	45.5	125	116	107
10	11.5	20.3	1.7	11.6	7.0	45.5	125	116	107
	Blade Assembly #3, Alundum 240 Grit Dust, Barometer 28.99 in. Hg.								
11	15.2	19.1	2.1	8.9	5.3	34.8	120	110	98
12	14.2	19.9	2.1	9.4	5.6	34.8	122	112	100
13	13.4	20.1	2.1	10.2	6.3	34.8	123	112	102
14	13.1	20.5	2.1	10.8	6.9	34.8	123	113	102
15	12.6	20.7	2.1	11.2	7.3	34.8	123	113	103
	Blade Assembly #4, Alundum 240 Grit Dust, Barometer 28.84 in. Hg.								
16	12.5	20.0	1.5	10.7	6.0	45.5	116	108	96
17	11.8	20.3	1.5	11.7	7.0	45.5	121	111	100
18	11.2	20.6	1.5	12.3	7.6	45.5	122	113	102
19	11.1	20.8	1.5	12.6	8.1	45.5	123	114	103
20	10.9	21.0	1.5	12.9	8.4	45.5	123	115	103
	Blade Assembly #5, Alundum 240 Grit Dust, Barometer 28.82 in. Hg.								
21	13.7	22.2	1.9	12.0	8.5	32.6	132	121	111
22	13.2	22.5	1.9	13.0	9.1	32.6	133	122	112
23	13.0	22.7	1.9	13.2	9.5	32.6	133	123	113
24	12.4	22.9	1.9	13.8	10.1	32.6	134	123	114
25	11.9	23.3	1.9	14.5	10.8	32.6	134	123	114

(Continued)

Table 1. Air Flow Data (Continued)

Run	h_1* (in.H_2O)	h_{s1} (in.H_2O)	h_2 (in.H_2O)	h_{s2} (in.H_2O)	h_{sRo} (in.H_2O)	R_o (cfm)	T_1 (F)	T_2 (F)	T_{Ro} (F)
Blade Assembly #6, Alundum 240 Grit Dust, Barometer 28.78 in. Hg.									
26	13.5	23.5	2.4	13.5	10.5	17.1	127	110	97
27	13.0	23.9	2.4	14.2	11.4	17.1	130	112	100
28	12.4	24.2	2.4	15.0	12.0	17.1	131	113	102
29	12.2	24.3	2.4	15.2	12.4	17.1	132	113	103
30	11.9	24.6	2.4	16.0	12.9	17.1	132	114	104
Blade Assembly #7, Alundum 240 Grit Dust, Barometer 28.82 in. Hg.									
31	14.9	21.4	1.4	10.5	6.2	41.2	130	121	110
32	14.1	22.0	1.4	11.5	7.3	41.2	131	121	111
33	13.7	22.2	1.4	12.0	7.9	41.2	132	122	112
34	13.2	22.5	1.4	12.8	8.0	41.2	132	122	112
35	12.8	22.7	1.4	13.0	8.7	41.2	132	122	113
Blade Assembly #8, Alundum 240 Grit Dust, Barometer 28.84 in. Hg.									
36	14.2	22.6	1.1	12.1	7.6	45.5	120	112	100
37	13.5	23.0	1.1	13.1	8.6	45.5	122	113	103
38	13.4	23.3	1.1	13.5	9.2	45.5	123	114	103
39	12.8	23.5	1.1	14.0	9.5	45.5	123	115	104
40	12.4	23.7	1.1	14.5	10.1	45.5	123	115	105
Blade Assembly #1, Microballons Dust, Barometer 28.86 in. Hg.									
41	13.7	24.0	2.7	14.0	9.4	32.6	120	111	99
42	13.0	24.3	2.7	14.9	10.2	32.6	120	111	100
43	12.3	24.7	2.7	15.8	11.3	32.6	124	112	103
44	11.8	25.1	2.7	16.6	12.2	32.6	126	115	105
45	11.0	25.5	2.7	17.6	12.8	32.6	128	117	107
Blade Assembly #2, Microballons Dust, Barometer 28.84 in. Hg.									
46	14.5	21.3	1.7	10.1	5.6	45.5	120	112	100
47	13.7	21.8	1.7	11.7	7.0	45.5	123	115	104
48	12.7	22.4	1.7	12.9	8.2	45.5	124	115	106
49	12.2	22.8	1.7	13.7	9.0	45.5	124	116	106
50	11.8	23.2	1.7	14.6	9.8	45.5	124	117	106

(Continued)

Table 1. Air Flow Data (Continued)

Run	h_1* (in. H_2O)	h_{s1} (in. H_2O)	h_2 (in. H_2O)	h_{s2} (in. H_2O)	h_{sRo} (in. H_2O)	R_o (cfm)	T_1 (F)	T_2 (F)	T_{Ro} (F)
	Blade Assembly #8, Microballons Dust, Barometer 28.91 in. Hg.								
51	14.0	21.9	1.1	10.5	7.2	45.5	119	111	100
52	13.8	22.5	1.1	13.0	8.6	45.5	121	113	102
53	12.2	22.9	1.1	14.0	9.6	45.5	124	115	104
54	10.7	24.0	1.1	16.4	11.2	45.5	126	117	106
55	10.3	24.3	1.1	16.8	12.2	45.5	126	117	106
	Blade Assembly #3, Alundum 240 Grit Dust, Barometer 28.96 in. Hg.								
56	15.5	20.7	1.8	9.0	5.9	32.6	124	113	102
57	13.8	20.0	1.9	9.6	5.9	32.6	124	112	102
58	10.8	17.2	2.1	8.9	5.0	32.6	122	112	100
59	8.9	16.8	2.8	9.4	4.7	32.6	122	110	100
60	7.6	16.6	4.4	9.6	3.3	32.6	124	111	100
	Blade Assembly #4, Alundum 240 Grit Dust, Barometer 28.92 in. Hg.								
61	14.5	22.1	1.4	11.5	6.7	45.5	122	113	100
62	12.7	20.8	1.7	11.2	6.1	45.5	120	112	102
63	10.8	18.9	2.2	10.5	5.2	45.5	122	112	102
64	7.9	17.5	3.7	10.3	3.3	45.5	123	113	103
	Blade Assembly #8, Alundum 240 Grit Dust, Barometer 28.92 in. Hg.								
65	14.8	22.9	1.0	12.1	7.5	45.5	122	113	100
66	13.3	21.8	1.1	11.7	7.2	45.5	120	112	102
67	11.3	19.9	2.4	10.8	5.8	45.5	122	114	102
68	9.2	18.0	2.6	10.0	3.9	45.5	120	113	102

*See Appendix A for meaning of symbols.

Table 2. Area of Test Housing at Louver Blade

Run	S_2 (in.)	A_2 (sq. in.)
1 thru 5	5.37	32.22
6 thru 10	5.13	30.78
11 thru 15	5.37	32.22
16 thru 20	4.68	28.08
21 thru 25	5.25	31.50
26 thru 30	5.25	31.50
31 thru 35	5.25	31.50
36 thru 40	4.81	28.86
41 thru 45	5.37	32.22
46 thru 50	5.13	30.78
51 thru 55	4.81	28.86
56	5.25	31.50
57	4.25	25.50
58	3.25	19.50
59	2.25	13.50
60	1.25	7.50
61	4.63	27.78
62	3.63	21.78
63	2.63	15.78
64	1.63	9.78
65	4.88	29.28
66	3.88	23.28
67	2.88	17.28
68	1.88	11.28

Table 3. Dust Flow Data

Run	Length of Run (sec.)	Dust in Inlet Air (grams)	Dust in Cleaned Air (grams)
Blade Assembly #1, Alundum 240 Grit Dust			
1	406	300	0.065
2	163	300	0.077
3	187	300	0.092
4	84	300	0.092
5	29	300	0.110
Blade Assembly #2, Alundum 240 Grit Dust			
6	308	300	0.076
7	212	300	0.078
8	101	300	0.090
9	56	300	0.098
10	29	300	0.114
Blade Assembly #3, Alundum 240 Grit Dust			
11	278	300	0.063
12	188	300	0.074
13	108	300	0.076
14	48	300	0.076
15	30	300	0.092
Blade Assembly #4, Alundum 240 Grit Dust			
16	249	300	0.023
17	167	300	0.026
18	125	300	0.033
19	49	300	0.032
20	25	300	0.033
Blade Assembly #5, Alundum 240 Grit Dust			
21	272	300	0.081
22	187	300	0.101
23	119	300	0.098
24	44	300	0.109
25	23	300	0.116

(Continued)

Table 3. Dust Flow Data (Continued)

Run	Length of Run (sec.)	Dust in Inlet Air (grams)	Dust in Cleaned Air (grams)
Blade Assembly #6, Alundum 240 Grit Dust			
26	233	300	0.100
27	176	300	0.101
28	130	300	0.110
29	43	300	0.117
30	37	300	0.119
Blade Assembly #7, Alundum 240 Grit Dust			
31	211	300	0.075
32	272	300	0.072
33	25	300	0.106
34	133	300	0.093
35	109	300	0.094
Blade Assembly #8, Alundum 240 Grit Dust			
36	252	300	0.015
37	179	300	0.003
38	113	300	0.002
39	49	300	0.010
40	25	300	0.016
Blade Assembly #1, Microballons Dust			
41	329	300	1.114
42	227	300	1.644
43	150	300	2.073
44	140	300	2.424
45	150	300	2.415
Blade Assembly #2, Microballons Dust			
46	150	300	0.817
47	231	300	1.016
48	134	300	1.251
49	85	300	1.547
50	78	300	1.656

(Continued)

Table 3. Dust Flow Data (Continued)

Run	Length of Run (sec.)	Dust in Inlet Air (grams)	Dust in Cleaned Air (grams)
Blade Assembly #8, Microballons Dust			
51	85	300	0.789
52	143	300	0.950
53	195	300	1.019
54	438	300	1.457
55	303	300	1.720
Blade Assembly #3, Alundum 240 Grit Dust			
56	67	600	0.089
57	56	480	0.054
58	47	360	0.070
59	40	250	0.048
60	20	125	0.032
Blade Assembly #4, Alundum 240 Grit Dust			
61	65	570	0.080
62	57	450	0.048
63	49	350	0.038
64	38	220	0.028
Blade Assembly #8, Alundum 240 Grit Dust			
65	64	600	0.117
66	53	480	0.081
67	41	370	0.042
68	33	250	0.049

Table 4. Air Flow Results

Run	W_1* (lb./sec.)	W_i (lb./sec.)	W_2 (lb./sec.)	W_3 (lb./sec.)	V_2 (ft./sec.)
	Blade Assembly #1, Alundum 240 Grit Dust				
1	0.580	0.0331	0.613	0.0382	39.9
2	0.565	0.0331	0.598	0.0379	39.1
3	0.559	0.0331	0.592	0.0379	38.7
4	0.549	0.0331	0.582	0.0379	38.0
5	0.545	0.0331	0.578	0.0379	37.7
	Blade Assembly #2, Alundum 240 Grit Dust				
6	0.545	0.0331	0.578	0.491	39.6
7	0.538	0.0331	0.571	0.491	39.0
8	0.524	0.0331	0.557	0.492	38.0
9	0.516	0.0331	0.549	0.484	37.5
10	0.511	0.0331	0.544	0.484	37.2
	Blade Assembly #3, Alundum 240 Grit Dust				
11	0.589	0.0331	0.622	0.0385	40.4
12	0.570	0.0331	0.603	0.0383	39.2
13	0.554	0.0331	0.587	0.0383	38.2
14	0.548	0.0331	0.581	0.0383	37.8
15	0.537	0.0331	0.570	0.0382	37.0
	Blade Assembly #4, Alundum 240 Grit Dust				
16	0.537	0.0331	0.570	0.0509	42.2
17	0.520	0.0331	0.553	0.0502	41.0
18	0.507	0.0331	0.540	0.0500	40.1
19	0.504	0.0331	0.537	0.0499	40.0
20	0.499	0.0331	0.532	0.0500	39.6
	Blade Assembly #5, Alundum 240 Grit Dust				
21	0.558	0.0331	0.591	0.0354	39.7
22	0.549	0.0331	0.582	0.0353	39.1
23	0.545	0.0331	0.578	0.0354	38.9
24	0.533	0.0331	0.566	0.0354	38.1
25	0.522	0.0331	0.555	0.0354	37.2

(Continued)

Table 4. Air Flow Results (Continued)

Run	W_1* (lb./sec.)	W_i (lb./sec.)	W_2 (lb./sec.)	W_3 (lb./sec.)	V_2 (ft./sec.)
	Blade Assembly #6, Alundum 240 Grit Dust				
26	0.555	0.0331	0.588	0.0194	38.6
27	0.542	0.0331	0.575	0.0192	37.8
28	0.532	0.0331	0.565	0.0191	37.2
29	0.527	0.0331	0.560	0.0189	36.8
30	0.520	0.0331	0.553	0.0189	36.4
	Blade Assembly #7, Alundum 240 Grit Dust				
31	0.580	0.0331	0.613	0.0443	41.4
32	0.565	0.0331	0.598	0.0445	40.3
33	0.558	0.0331	0.591	0.0446	39.8
34	0.548	0.0331	0.581	0.0446	39.1
35	0.540	0.0331	0.573	0.0446	38.5
	Blade Assembly #8, Alundum 240 Grit Dust				
36	0.572	0.0331	0.605	0.0503	43.6
37	0.558	0.0331	0.591	0.0502	42.7
38	0.555	0.0331	0.588	0.0502	42.5
39	0.543	0.0331	0.576	0.0502	41.6
40	0.534	0.0331	0.567	0.0502	41.0
	Blade Assembly #1, Microballons Dust				
41	0.563	0.0331	0.596	0.0357	38.3
42	0.548	0.0331	0.581	0.0358	37.3
43	0.532	0.0331	0.565	0.0356	36.2
44	0.521	0.0331	0.554	0.0356	35.7
45	0.503	0.0331	0.536	0.0355	34.5
	Blade Assembly #2, Microballons Dust				
46	0.577	0.0331	0.610	0.0502	41.5
47	0.563	0.0331	0.596	0.0498	40.6
48	0.540	0.0331	0.573	0.0497	38.9
49	0.528	0.0331	0.561	0.0496	38.1
50	0.521	0.0331	0.554	0.0499	37.6

(Continued)

Table 4. Air Flow Results (Continued)

Run	W_1* (lb./sec.)	W_i (lb./sec.)	W_2 (lb./sec.)	W_3 (lb./sec.)	V_2 (ft./sec.)
	Blade Assembly #8, Microballons Dust				
51	0.568	0.0331	0.601	0.0503	43.4
52	0.563	0.0331	0.596	0.0501	43.0
53	0.529	0.0331	0.562	0.0502	40.6
54	0.495	0.0331	0.528	0.0503	38.1
55	0.486	0.0331	0.519	0.0505	37.4
	Blade Assembly #3, Alundum 240 Grit Dust				
56	0.594	0.0331	0.627	0.0357	41.9
57	0.561	0.0331	0.594	0.0357	48.8
58	0.496	0.0331	0.529	0.0358	56.9
59	0.450	0.0331	0.483	0.0356	74.8
60	0.415	0.0331	0.448	0.0355	125.
	Blade Assembly #4, Alundum 240 Grit Dust				
61	0.577	0.0331	0.610	0.0502	45.9
62	0.540	0.0331	0.573	0.0498	54.9
63	0.497	0.0331	0.530	0.0497	70.2
64	0.424	0.0331	0.457	0.0493	97.9
	Blade Assembly #8, Alundum 240 Grit Dust				
65	0.583	0.0331	0.616	0.0504	43.9
66	0.553	0.0331	0.586	0.0501	52.4
67	0.509	0.0331	0.542	0.0497	65.8
68	0.458	0.0331	0.491	0.0494	91.4

*See Appendix A for meaning of symbols.

Table 5. Dust Concentration

Run	G_2* (lb./sec.)	G_3 (lb./sec.)	c_2 (lb./lb.)	c_3 (lb./lb.)	Eff. (%)
	Blade Assembly #1, Alundum 240 Grit Dust				
1	0.001629	0.0000003522	0.002657	0.000009220	99.65
2	0.004058	0.000001043	0.006785	0.00002751	99.59
3	0.003537	0.000001085	0.005975	0.00002863	99.52
4	0.007876	0.000002416	0.01353	0.00006374	99.52
5	0.02281	0.000008379	0.03946	0.0002211	99.44
	Blade Assembly #2, Alundum 240 Grit Dust				
6	0.002141	0.0000005455	0.003704	0.00001110	99.70
7	0.003120	0.0000008113	0.005464	0.00001652	99.70
8	0.006550	0.000001960	0.01176	0.00003984	99.66
9	0.01181	0.000003857	0.02151	0.00008002	99.63
10	0.02281	0.000008655	0.04193	0.0001788	99.57
	Blade Assembly #3, Alundum 240 Grit Dust				
11	0.002379	0.0000005000	0.003825	0.00001299	99.70
12	0.003519	0.0000008670	0.005836	0.00002264	99.61
13	0.006126	0.000001556	0.01044	0.00004062	99.61
14	0.01378	0.000003500	0.02372	0.00009138	99.61
15	0.02205	0.000006766	0.03868	0.0001771	99.54
	Blade Assembly #4, Alundum 240 Grit Dust				
16	0.002657	0.0000002036	0.004661	0.000004060	99.91
17	0.003961	0.0000003431	0.007163	0.000006835	99.90
18	0.005292	0.0000005824	0.009800	0.00001164	99.89
19	0.01350	0.000001441	0.02514	0.00002887	99.88
20	0.02646	0.000002912	0.04974	0.00005824	99.88
	Blade Assembly #5, Alundum 240 Grit Dust				
21	0.002432	0.0000006581	0.004112	0.00001859	99.55
22	0.003537	0.000001192	0.006077	0.00003376	99.44
23	0.005558	0.000001815	0.009616	0.00005127	99.47
24	0.01504	0.000005454	0.02657	0.0001541	99.42
25	0.02876	0.00001113	0.05182	0.0003144	99.39

(Continued)

Table 5. Dust Concentration (Continued)

Run	G_2* (lb./sec.)	G_3 (lb./sec.)	c_2 (lb./lb.)	c_3 (lb./lb.)	Eff. (%)
	Blade Assembly #6, Alundum 240 Grit Dust				
26	0.002839	0.0000009464	0.004828	0.00004876	98.99
27	0.003758	0.000001265	0.006536	0.00006588	98.99
28	0.005088	0.000001866	0.009005	0.00009769	98.91
29	0.01538	0.000006000	0.02746	0.0003175	98.84
30	0.01788	0.000007092	0.03233	0.0003752	98.84
	Blade Assembly #7, Alundum 240 Grit Dust				
31	0.003135	0.0000007819	0.005114	0.00001765	99.65
32	0.002432	0.0000005845	0.004066	0.00001312	99.65
33	0.02644	0.000009360	0.04474	0.0002099	99.53
34	0.004974	0.000001541	0.008561	0.00003455	99.59
35	0.006069	0.000001899	0.01059	0.00004257	99.60
	Blade Assembly #8, Alundum 240 Grit Dust				
36	0.002625	0.0000001313	0.004339	0.000002610	99.94
37	0.003685	0.00000003687	0.006235	0.0000007344	99.99
38	0.005854	0.00000001946	0.009956	0.0000003876	99.99
39	0.01378	0.0000004583	0.02392	0.000009129	99.96
40	0.02646	0.000001412	0.04667	0.00002813	99.94
	Blade Assembly #1, Microballons Dust				
41	0.002011	0.000007465	0.003372	0.0002091	93.80
42	0.002914	0.00001597	0.005009	0.0004461	91.09
43	0.004410	0.00003047	0.007805	0.0008560	89.03
44	0.004725	0.00003818	0.008529	0.001072	87.44
45	0.004410	0.00003550	0.008228	0.001000	87.85
	Blade Assembly #2, Microballons Dust				
46	0.004410	0.00001201	0.007229	0.0002392	96.70
47	0.002863	0.000009698	0.004804	0.0001947	95.94
48	0.004936	0.00002059	0.008614	0.0004142	95.20
49	0.007782	0.00004013	0.01387	0.0008091	94.17
50	0.008480	0.00004681	0.01531	0.0009381	93.87

(Continued)

Table 5. Dust Concentration (Continued)

Run	G_2* (lb./sec.)	G_3 (lb./sec.)	c_2 (lb./lb.)	c_3 (lb./lb.)	Eff. (%)
	Blade Assembly #8, Microballons Dust				
51	0.007782	0.00002047	0.01294	0.0004070	96.86
52	0.004626	0.00001465	0.007768	0.0002924	96.24
53	0.003392	0.00001152	0.006032	0.0002291	96.20
54	0.001510	0.000007336	0.002860	0.0001458	94.90
55	0.002183	0.00001252	0.004200	0.0002479	94.09
	Blade Assembly #3, Alundum 240 Grit Dust				
56	0.02006	0.000002928	0.03199	0.00008202	99.74
57	0.01892	0.000002127	0.03185	0.00005958	99.81
58	0.01690	0.000003285	0.03195	0.00009176	99.71
59	0.01378	0.000002645	0.02853	0.00007429	99.73
60	0.01378	0.000003525	0.03076	0.00009930	99.67
	Blade Assembly #4, Alundum 240 Grit Dust				
61	0.01936	0.000002714	0.03174	0.00005406	99.83
62	0.01741	0.000001856	0.03038	0.00003727	99.87
63	0.01574	0.000001710	0.02970	0.00003441	99.88
64	0.01278	0.000001624	0.02796	0.00003294	99.88
	Blade Assembly #8, Alundum 240 Grit Dust				
65	0.02069	0.000004031	0.03359	0.00007998	99.76
66	0.01997	0.000003369	0.03408	0.00006724	99.80
67	0.01988	0.000002259	0.03668	0.00004545	99.87
68	0.01672	0.000003273	0.03405	0.00006626	99.80

*See Appendix A for meaning of symbols.

Table 6. Unaccountable Weight Change in Filter Bags

Run	Length of Run (sec.)	Bag Weight Before Run (grams)	Bag Weight After Run (grams)	Unaccountable Weight Change (grams)
A	60	29.852	29.846	- 0.006
B	120	31.777	31.776	- 0.001
C	180	31.641	31.645	0.004
D	240	31.794	31.780	- 0.014
E	300	30.322	30.316	- 0.006

APPENDIX D

DETERMINATION OF AIR FLOW RESULTS

Determination of Inlet Air Flow.—The orifice meter used to measure the inlet air was constructed by the Foxboro Company in accordance with the specifications for thin plate orifices given in the A.S.M.E. Research Committee Report on Fluid Meters. (7) Standard flange pressure taps were used with the taps being located one inch upstream and one inch downstream from the orifice plate.

The flow equation for the thin plate orifice is

$$W_1 = 0.0997 \frac{C}{\sqrt{1 - \beta^4}} D_2^{\,2} \sqrt{\rho_1 h_{s1}}$$

where

W_1 = mass flow rate — lb./sec.

C = coefficient of discharge

D_2 = orifice diameter — in.

β = D_2/D_1

D_1 = pipe diameter — in.

ρ_1 = upstream air density — lb./cu.ft.

h_{s1} = orifice pressure differential — in. H_2O

The Fluid Meters Report gives experimentally determined values for the expression

$$\frac{C}{\sqrt{1 - \beta^4}} = K$$

based on the pipe size and the Reynolds number. It was estimated that the mass flow rate would be between 0.4 lb./sec. and 0.6 lb./sec. and the resulting Reynolds were from 85000 to 125000. For this range of Reynolds numbers and for the pipe size and D_2/D_1 ratio used the value for K was given as 0.6276.

To facilitate solution of the flow equation two curves were plotted. The first of these, Figure 24, was a plot of air density, ρ_1, versus static pressure in inches of water with the temperature as a parameter. A barometric pressure was used in the construction of the curve and any variation from this was accounted for by adjusting the static pressure. The density is given by the expression

$$\rho_1 = \frac{144\ h_{s1}}{R\ T_1}$$

where h_{s1} = upstream static pressure, inlet air orifice

R = the gas constant for air, 53.3

T_1 = upstream temperature, inlet air orifice, degrees Rankin

The second curve, Figure 25, is a plot of mass flow, W_1, versus the product, $\rho_1\ h_{s1}$. By use of these two curves the mass flow rate through the inlet air orifice could be determined rapidly and with an accuracy of three significant figures.

Determination of Air Flow through the Dust Injector.—The flow of air through the nozzle of the dust injector was computed by the equation (8),

$$W_i = 0.53\ C_i p_{i1}\ \frac{A_{i2}}{\sqrt{T_{i1}}}$$

where

W_i = mass flow rate — lb./sec.

C_i = coefficient of discharge

p_{i1} = upstream air pressure — lb./sq.ft., absolute

A_{i2} = throat area of nozzle — sq.ft.

T_{i1} = upstream air temperature — degrees Rankin

D_{i2} = diameter of nozzle throat — in.

and for the nozzle used

C_i = 0.975

p_{i1} = 25 lb./sq.in., gage

D_{i2} = 0.221 in.

T_{i1} = 90 degrees F.

Average barometer reading = 28.9 in. Hg.

The mass flow rate through the nozzle therefore is

$$W_i = \frac{0.53 \times 0.975\ (25 + 28.90 \times 0.491)\ 144 \times \pi \times (0.221)^2}{4 \times 144 \sqrt{90 + 460}}$$

W_i = 0.0331 lb./sec.

Determination of Flow Rate of Cleaned Air.—The flow of cleaned air was measured with a Schutte and Koerting Rotameter provided with a scale graduated in cubic feet per minute at a standard flow condition of 100 degrees Fahrenheit and 50 inches of water pressure.

During the tests the rotameter readings and the temperature and pressure of the air entering the rotameter were recorded. The rotameter reading was then corrected by formulae provided by the manufacturer. The temperature correction multiplicity factor was

$$K_t = \sqrt{\frac{T_c}{T_{Ro}}}$$

where T_c = rotameter calibration temperature — degrees Rankin

T_{Ro} = measured air temperature — degrees Rankin

The pressure correction multiplicity factor was

$$K_p = \sqrt{\frac{h_{sRo}}{P_c}}$$

where P_c = rotameter calibration pressure — lb./sq.in., absolute

h_{sRo} = measured air pressure — lb./sq.in., absolute

By use of these two correction factors the corrected flow rate in cubic feet per minute was obtained.

By use of the pressure - density chart, Figure 24, the density, ρ_3, of the air flowing through the rotameter was determined and the weight of air flowing per second was given by the expression

$$W_3 = \frac{R_o \text{ (corrected)}}{60} \times \rho_3$$

where

$\bar{W}_3$ = mass flow rate of cleaned air — lb./sec.

R_o = rotameter reading — cu.ft./min.

ρ_3 = cleaned air density — lb./cu.ft.

APPENDIX E

CALCULATION OF OVERALL EFFICIENCY

CALCULATION OF OVERALL EFFICIENCY

The overall efficiency of a hypothetical louver type dust separator consisting of 9 blades and designed to operate with 10 per cent blowdown is computed in the tabulation below. The operating conditions for the separator are

Efficiency of each louver blade -- 99 per cent

Mass of inlet air -- 1000 lbs. per unit time

Mass of inlet dust -- 1 lb. per unit time

Mass of air removed at each louver blade -- 100 lbs. per unit time

Blade No.	Mass of Air at Blade/ Unit Time (lbs.)	Mass of Dust at Blade/ Unit Time (lbs.)	Mass of Clean Air Removed (lbs.)	Mass of Dust in Clean Air (lbs.)	Total Mass of Dust in Clean Air (lbs.)
1	1000	1.000000	100	0.00100000	0.00000000
2	900	0.999000	100	0.00111000	0.00211000
3	800	0.997890	100	0.00124736	0.00335736
4	700	0.996643	100	0.00142377	0.00478113
5	600	0.995218	100	0.00165869	0.00643982
6	500	0.993560	100	0.00198712	0.00842694
7	400	0.991573	100	0.00247893	0.01090587
8	300	0.989194	100	0.00329731	0.01420318
9	200	0.985796	100	0.00492898	0.01913216

Since a total of 900 lbs. of air has been cleaned and this air originally contained 0.9 lbs. of dust and contains 0.01913216 lbs. of dust after being cleaned the overall efficiency of this separator is

$$\text{Overall efficiency} = \frac{0.90000000 - 0.01913216}{0.9} \times 100 = 97.87\%$$

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